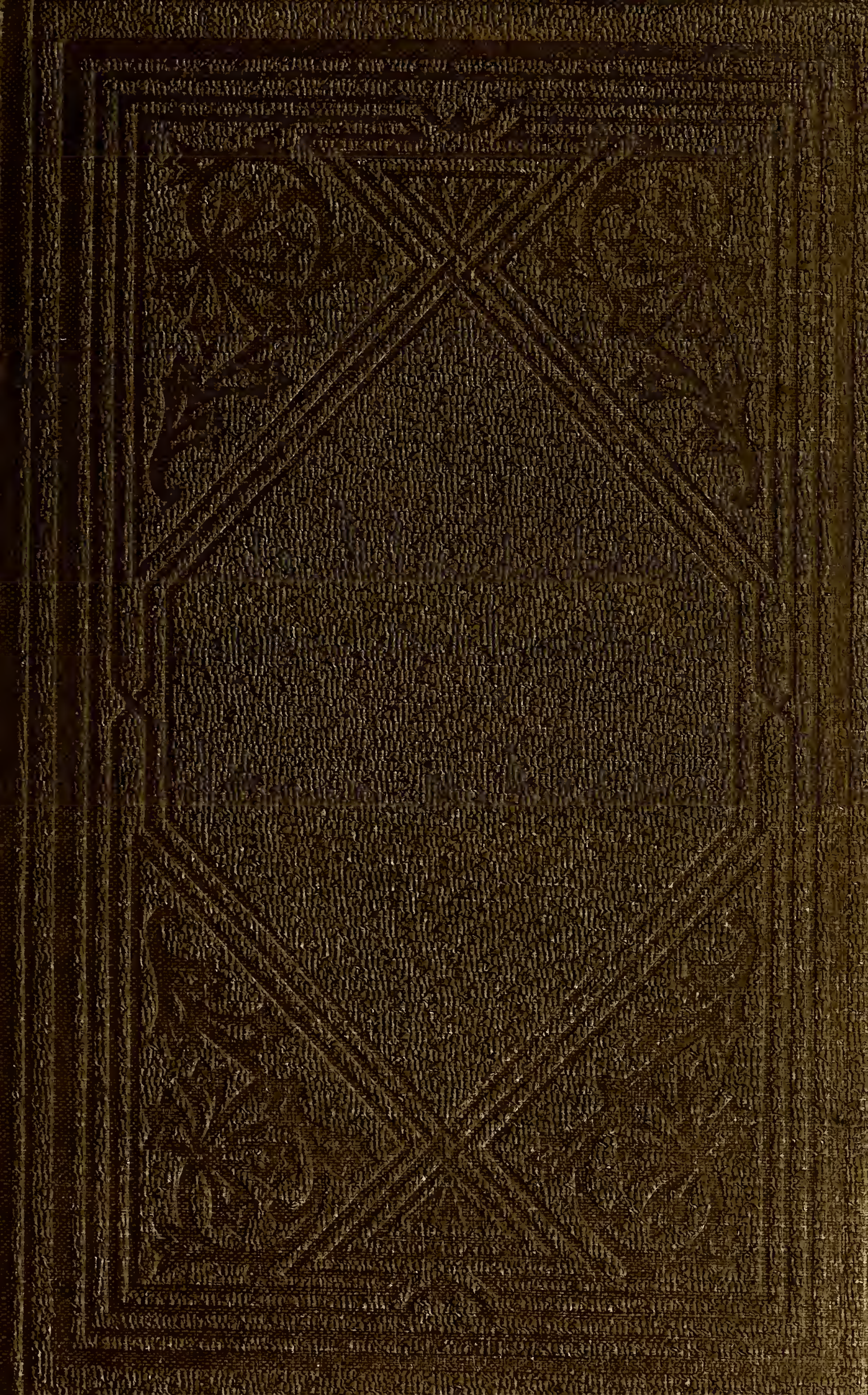

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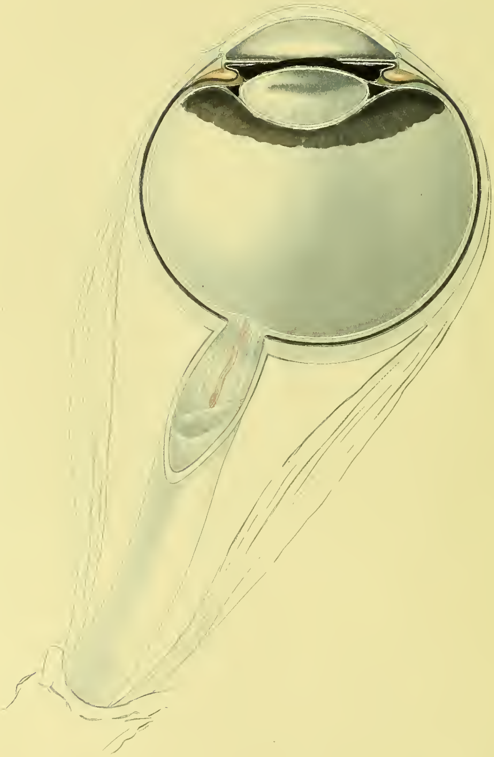

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ENTOPTICS,

WITH ITS USES IN

PHYSIOLOGY AND MEDICINE.

BY

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PREFACE.

I DEEM it but fair to myself and to the reader that he should know for how long and how far I have devoted attention to entoptical studies.

In the year 1841, when I was still, as to medicine, *in statu pupillari*, I was tempted to press strongly upon the eyeballs in testing some physiological fancy suggested to me in the course of my reading; and having a few days afterwards become aware, for the first time in my life, that my eyes were inhabited by muscæ volitantes, I consulted an eminent oculist about them. Whilst cheering me with the assurance that they might prove innocuous, he enjoined me to abstain for a time from books, lest they should perchance turn out to be premonitory of amaurosis. Being shut out from reading, I had no refuge but in thinking. After some endeavour to bear with patience the interruption of my studies, I commenced examining the muscæ with a punctured card, and inviting my acquaintances to search their eyes in the same way. I soon convinced myself that such muscæ are the common lot of mankind. Whilst visiting several medical schools and many hospitals, before and after my graduation in medicine, I rarely neglected an opportunity of accumulating evidence upon this point.

It was only in a time of leisure that it occurred to

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It was only in a time of leisure that it occurred to me that it might not be amiss to submit to the profession the results I had arrived at. This I did in 1845, in an entoptical paper cited at p. 113.

After this, for nine or ten years entoptics occupied but a little of my thoughts, when some events in my professional pursuits aroused a fresh desire to become better informed upon the accidental phenomena of vision.

For some months I gave up much of my spare time to this purpose; but only to see the field of observation continually expanding. Insomuch that, despairing of its exploration, I published such thoughts or conjectures as I had entertained, under the hope that some might prove useful, expecting that I should bid the inquiry a final farewell. In fact, grudging the absorption of too much of my time in this way, I had retrograded from my first entoptical essay, in precision of aim, and slurred over much of the subject in an indefinite style.

However, while I was thus engaged, or while I had not been on the alert after entoptical writings, others had laboured in the same field; and a few in a stricter form of demonstration than I had latterly used. An article in a German Encyclopædia (Karsten's), which appeared shortly after my last essay, put me on the track of this literature.

Its perusal, nevertheless, disappointed me: for, according to my apprehension, though the abilities of several of the contributors were great, the subject had, for the most part, been handled but clumsily and defectively; and I was persuaded that the crude conceptions at the bottom of my last essay would, if duly elaborated, be much more efficient in the promotion of the study. On my trying my hand at putting them into an exact form, I found the task easier than I had anticipated, and, to my surprise, that it made less demands upon my time to carry on entoptical researches in a strict than in a loose mode.

In 1859, there appeared an article of mine, entitled Entoptics, in the Medico-Chirurgical Review, which strove to fulfil some of the stricter requirements I contemplated. It was, however, too sparingly illustrated with drawings, too summary, and, in a few instances, too hasty in its statement of facts, to achieve the object I had at heart. Nor do I flatter myself that I shall altogether achieve it now.

But I have exerted myself to make this little work, as near as may be, a treatise on Entoptics; which, in dealing with the subject primarily from my own point of view, does not fail to make the reader acquainted with the views of other writers. It also contains a number of woodcuts, all of which, except three,* are from original drawings; and many of them unique attempts to illustrate the phenomena referred to. It ventures, too, upon untrodden ground in its investigations, and to suggest explanations of phenomena that have remained unaccounted for: many of its physiological conclusions are peculiar. That is, in every sense, in the main, it is an original essay.

In my wish to aid in the advancement of Physiological Optics, I have founded my reasoning upon formulæ for calculations, which are first of all as strictly just as I could make them,—next, as simple.

* Figs. 4, 5, 8.

The frontispiece is not from my own hand; and though the drawings in the introduction are, two or three of them, of course, I do not claim as being from original investigations.

For those who are not trained in such reasoning I have put their imports into words; or shown them by diagrams: especially I have been liberal in sketches of the actual appearances described.

But it is to the intelligent medical practitioner that I would fain make this essay acceptable. Whoever is accomplished in the entoptical exploration of his own eyes need be little puzzled in guiding a patient of average understanding so to explore his, as often to obtain information, not otherwise obtainable, which may be of great value to the medical or surgical adviser. Many a time have I succeeded in setting the minds of patients at rest, who have been under a load of concern about some of the accidental phenomena of vision, of whose presence they have become conscious, by sketching with a pencil the appearances they described. The drawings in this book, it is hoped, will be found available in this way. I have more than once been able to sketch appearances arising to the patient, so as to meet his approval, from pathological conditions of the eye, simply as entoptical inferences from a correct diagnosis obtained by other means, and thus helped to confirm it. To judge with safety of pathological symptoms, we should be able to eliminate the physiological.

Often, as has been just hinted, where there is no ocular disease, the physician feels it a privilege to be acquainted with the characteristics of the different entoptical phenomena; inasmuch as these frequently become the occasion of such solicitude to patients of failing health as to be a strong bar against recovery; and worse still, should these be regarded as symptoms of disease in the eye itself. "It is," says a recent surgical writer on the eye (as quoted at end of p. 127), "lamentable to meet with patients who have gone through years of treatment, often of the severest kind,—even to bleeding and salivation,—or at best through an equally ineffectual course of tonics and local applications, and after all have remained with their muscæ undiminished, and their minds still burdened with anxiety and fears of approaching blindness." It is not on account of muscæ alone that a want of knowledge of the kind here advocated has chained patients with no abnormal condition of vision to a life of inactivity and misery. Then there is another side which makes almost a stronger appeal to our sympathies, namely, where, as is highly probable, patients have been condemned as malingerers, who would have received acquittal had their medical judges this sort of, in addition to their other, knowledge.

A writer on Physiological Optics (as cited at p. 116), who is not of the medical profession, says of us :—"In the ordinary diseases to which the eye, like other parts of the body is subject, we may safely confide in the skill of the experienced physician; but in the diseases to which it is liable as an optical instrument, where optical science can alone direct us, we regret that professional assistance is difficult to be found. Guided by practice, the skilful oculist may dexterously extract the crystalline lens, or make an artificial pupil; but all the refinements of optical science are requisite in the practitioner to whom we commit the care of our sight; and we trust the time is not distant when men will be expressly educated for this branch of the healing art, and exhaust in their practice the rich resources with which science can supply them."

At present the English reader meets with nothing but fragmentary entoptical writings,—he has no access to the subject treated as a whole. That is (irrespective of any contributions from the pen of the present writer), there is no book which can be said to put him in possession of what has been published on it. The convenience of the foreign reader seems but little better provided for. Entoptics has a pretty well defined boundary, and occupies too much scope to be unfolded in a few pages in a work on Physiological Optics, or in one on Diseases of the Eye. In dealing with it as a separate subject, I have hoped to furnish a ready introduction to the study to those who are desirous of embarking in it, and thus to aid a little way on their road those who are ambitious of attaining to the acquirements we have just been told that some among us should possess.

I have taken trouble to get a look at all such works of any prominence as bear upon the subject, and I think the reader will admit that I could scarcely have been expected to have accomplished more in that way. I have plainly consulted more original writings on Entoptics than the writer in the Encyclopædia, who honestly points out those he has referred to himself among the much larger number he notices. I shall follow this good example: I will always state explicitly that I only quote through an intermediate author whenever that happens to be the case.

May 23, 1864.

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CORRIGENDA.

PAGE
7, line 9, *for* $\frac{1}{10}$ *read* $\frac{1}{7}$.
11, ,, 12, after convex insert convergent.
16, ,, 7, *for* FG. *read* EG.
17, ,, 6, *for* their *read* the.
28, in footnotes, *for* § *read* S.
44, line 5 from bottom, *for* those *read* these, and erase the comma.
,, ,, 6 ,, ,, erase comma, and insert comma after bracket.
50, last footnote, *for* ss *read* SS.
60, last line, *for* ertical *read* vertical.
107, line 4, *for* others *read* another.
115, lines 7 and 10, *for* Muscæ *read* Musca.
134, line 2, *for* thesehave *read* these have.
139, ,, 13, fraction, add mark of bracket at end of denominator.
,, ,, 17, fraction, erase mark of bracket in the numerator, and place the minus of the denominator as in the numerator of the following fraction.
149, line 7, *for* variou *read* various.

ENTOPTICS.

CHAPTER I.

INTRODUCTION.

1. The anatomist, armed with the microscope, is still unremitting in his efforts to arrive at nicer knowledge of the structure of the human eye; the mathematician never wearies in revising the abstruse calculations by which he seeks to reconcile the phenomena of vision with the laws of physical optics; whilst crowds of observers have made investigations into the properties of the retina, and the laws by which the mind perceives retinal images.

I do not design in this little essay to treat generally of the anatomy of the organ of vision, nor of physiological optics in the comprehensive sense just alluded to, though I shall have occasion to enter minutely into certain principal questions commonly embraced under one or other of these heads.

The eye is provided with a mechanism by which it rotates in its socket. It is covered with a lubricating fluid, over which glide protective shields. It is formed of a series of lenses, some of which are complex in their structure. It contains a muscular diaphragm for regulating the admission of light, besides a muscle for adjusting its lenticular system for the view of objects at different distances from it. The retina itself is composed of various tissues, and is nourished by blood-vessels which in reality fall within the refracting media. Even this is a very defective enumeration of the many contrivances that combine to give greater efficiency to the organ of sight.

We need not be surprised to find that, amidst all the the advantages accruing from such aggregation of machinery, some inconveniences arise,—that the functions of the component parts are not always performed with absolute perfection, or that the existence of one part may sometimes prove detrimental to the due action of another. It is the irregularities of vision that I am chiefly about to consider, especially a number of adventitious phenomena—spectres, as I have elsewhere called them—whether caused by incidental interruptions to the course of light that falls upon the eye, or to any mechanical pressure that excites or blunts the sentient nervous expansion, whose proper office it is to receive the impressions of light. Besides the ordinary interest that we feel in tracing subjective illusions to their sources, the accurate elimination of these is a physiological necessity, if we would avoid the risk of ascribing effects begotten by subordinate to more integral portions of the apparatus, and thus of forming wrong conceptions of the laws which regulate the conduct of the latter. Finally, a diligent study of these accidental appearances may be made serviceable for the solution of certain important points of ocular structure of too delicate a nature for the microscope or other usual means of investigation; as also for determining important questions of function.

We may thus regard "Ocular Spectres, Structures, and Functions, as mutual Exponents." It will be my endeavour to show geometrically that they are so; whilst I shall be led to discuss a few other points in physiological optics not open to such a mode of treatment, for the sake of enforcing my general arguments or of limiting their application.

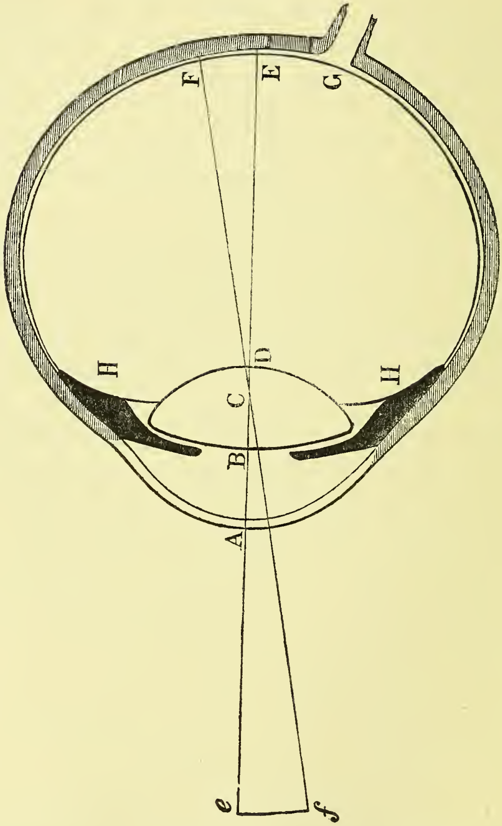
With the view of facilitating the study for such of my readers as may not hitherto have paid close attention to physiological optics, I shall begin by briefly touching upon a few leading properties of the eye, which I shall have occasion to refer to in the sequel.

2. The eyeball may be approximately described as being of a spheroidal form, whose shorter axis corresponds to the axis of vision, a small portion of the opaque sclerotic coat which gives this form being absent around this axis in front, where the transparent cornea projects in continuation of it, having the form of a segment of a smaller spheroid whose longer axis coincides with the axis of vision.

The refracting media of the eye, taken in order from before backwards, are, the cornea, aqueous humour, crystalline lens, and vitreous humour.

The accompanying figure represents a magnified section of the right eye through its axis and point of entrance of the optic nerve; and, although it be not strictly correct to say so, we may regard the four lenses above mentioned as symmetrically constructed about the axis; so that this section, omitting the indication of the optic nerve, will answer as well for any other as the transverse one. It will be observed that the crystalline is a double convex lens, but projecting much more behind than before, which form necessarily makes each

FIG. 1.

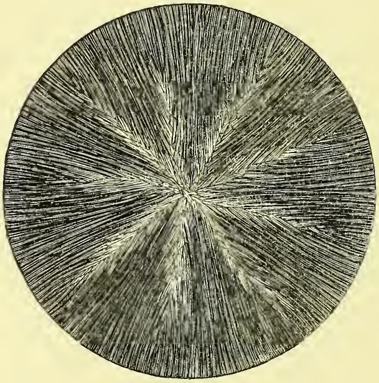


of the humours concave on one of its surfaces. The aqueous used to be described as consisting of two chambers, one anterior and one posterior to the iris. The iris is sketched in the figure almost close to the crystalline, so as to nearly obliterate the posterior chamber; since, from some recent investigations of Cramer and Helmholtz, it has been held that the iris is ordinarily in contact with it, or, at any rate, all but so.

3. However, it is not accurate to say that the lenses of the eye are only four; because the crystalline increases in density from its circumference to its centre, being made up of concentric coats, something like what we see in the onion. These coats consist of minute tubes, which are of given lengths, and fuse together at their ends in a few granular lamellæ, which twist and branch in the substance of the lens, so as to emerge on its anterior and posterior faces, in the adult eye, in the shape of two stars that do not exactly resemble each other. The points from which the radiations take place may not be precisely in the axis of the eye, or this may deviate a little from the structural vertices of the lens. The stars may show from nine to sixteen rays each, those of the anterior one being commonly the more distinct. In the fœtus the star shows three main limbs about 120° apart, the lamellæ being rotated in traversing the lens through 60°, so that the main limbs of the posterior star are intermediate to those of the other. The lens is enclosed in a membranous capsule. Fig. 2 indicates nine rays on the anterior aspect of the lens.

The hyaloid membrane lining the retina, and blending with the capsule of the lens in front, forms a capsule for the vitreous body. It has been an unsettled question what is the character of the internal structure of this body, or if it has any. The fluid of which it, at least mainly, consists, has been compared to the white of an egg and to mucus, and has been hitherto regarded as homogeneous throughout.

Fig. 2.



In Chapter VI. the question of the structure of the vitreous humour will be particularly discussed.

But, this apart, we may add that the rays of light suffer refraction at the coating of fluid that lubricates the cornea before they reach its surface.

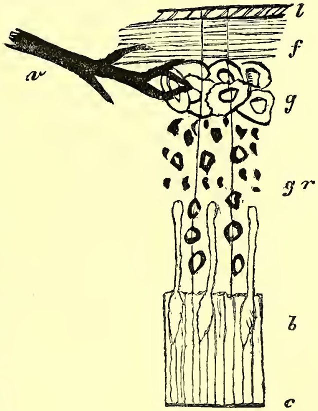
Moreover, the retina (except at a minute depression about $\frac{1}{25}$th of an inch in diameter, just in the axis of vision, named the foramen centrale, where it is exceedingly thin) presents several distinct strata in the course of the rays of light—stratum limitans, s. fibrillosum, s. gangliosum, s. granulosum—before they can reach its outermost one, which is esteemed the true sentient,—s. bacillosum.

We will append, parenthetically to our notes on the refractive media, such others on the structure of the eye as may be useful to us hereafter. The plate at the beginning of the book may be referred to as a section of the eye similarly conceived to the figure, but indicating some structures omitted by it: neither can display such as are only visible with the microscope.

Fig. 3 is a magnified skeleton view of a perpendicular section of the retina from the hyaloid to the choroid, with a vessel running into it.*

The point of entrance of the optic nerve into the eye is about $\frac{1}{10}$th of an inch from the optic axis. The yellow spot of the retina has a diameter of full $\frac{1}{5}$th of an inch,—that is, it extends all round the central hole to $\frac{1}{10}$th. According to Kölliker, "the vessels of the retina are derived from the art. centralis retinæ, which enters the eye enclosed in the optic nerve, and begins to ramify from the centre of the *colliculus nervi optici* in four or five main branches. Lodged at first only beneath the *membrana limitans*, these vessels penetrate through the layer of nerve-fibres into that of grey nerve-substance, ramify in an elegant arborescent manner as far as the *ora serrata*, and pass by their terminal pro-

Fig. 3.



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* The initial letters at the middle of the strata speak for themselves. The fibrillose layer is the expansion of the optic nerve; the next is grey nervous matter; the next consists of variously-sized corpuscles. The bacillar layer is constituted of rods and cones, the latter of which send attenuated prolongations into the layer within, and the former are united by a fibre each to the limitary membrane.

longations on all sides into a rather wide-meshed network of very fine capillaries (0·002 – ·003 French lines), which is lodged chiefly in the grey layer, but partly also in the expansion of the optic nerve."

In the frontispiece may be observed the ciliary processes, muscle, and ligament. The retina, resting immediately upon the choroid coat, whose pigment may be seen through it, encloses from the *ora serrata* at the ciliary processes the vitreous body; the limiting membrane of the retina being lined by the hyaloid.

4. To return to our consideration of the refracting media, it is obvious that the scheme of the eye involves so many lenses that it would be possible in no individual instance to follow a ray of light through all the refractions it undergoes in permeating it: we can only approximate.

The refractive power of the cornea just slightly exceeds that of water, or the aqueous humour. The indices of refraction for the chief separating surfaces have been determined as follows.*

From air to aqueous humour	1·3366
From latter to outer coat of crystalline lens .	1·0466
From vitreous humour to ditto .	1·0445

Thus a ray suffers a much greater refraction at the cornea than it does at the crystalline, the densest medium.

5. When the eye—a convex lens—paints an inverted image of some external object upon the middle parts of the retina, and we draw lines from every point of the object straight to its corresponding point of the image, these lines will intersect the optic axis, and each other

---

* Brewster's Optics, p. 408.

sufficiently nearly at one point that we may esteem them as doing so; and this point we may look upon as the lenticular centre of the eye. Great pains have been bestowed in determining the position of this point, both by elaborate investigations into the properties of the ocular lenses, and by experimental observation upon dead and living eyes. The greater weight of evidence places it in the interior of the crystalline lens, not far from its posterior surface. Thus *e* E being the optic axis (axis of vision) in Fig. 1, and *e f* (drawn, to save space, too near the eye for distinct vision) an object projecting laterally from it, and E F its retinal image, C where *f* F crosses *e* E is the lenticular centre of the eye.

It must be remembered, however, that in order to see the points *e* and *f* in their true directions, the retinal law of vision must be such that we see them in the directions E *e* and F *f*. There is every reason for believing that the mind does project all sensations of the retina in normals to its surface at the points affected. This law is found to be equivalent to seeing in directions passing through C for the more middle parts of the retina; though, for more eccentric parts, it undoubtedly gives rise to a certain amount of error or parallax of vision. For all the purposes of this essay, we may regard C as also the optic centre of the eye, and C E as the optic radius.

6. We may take the length of the optic axis A E at $\frac{5}{6}$, of the optic radius C E at $\frac{3}{5}$, the distance of the optic centre from the eye's surface C A at $\frac{7}{30}$ of an inch; whilst the depth of the vitreous humour is $\frac{2}{3}$, of the crystalline lens $\frac{1}{6}$, and of the aqueous humour

and cornea together also $\frac{1}{6}$ of the length of the optic axis.*

Hence, if $e\ f$ subtend a small angle at C, and we measure C E in inches, we have the proportion—

$$e f : \mathrm{E\,F} :: e\,\mathrm{C} :: \mathrm{E\,C}.$$

Or,—

Length of object : that of image :: inches of object from optic centre : $\frac{3}{5}$.

Thus, if there be an image on the retina from any cause existing within the eye, we have only to note its apparent length upon a surface which is perpendicular to the optic axis, at an ascertained distance from the eye, to be able to find its actual.

We can equally well get the actual length of the image if we know the number of degrees its apparent subtends at the optic centre; for we have—

E F : circumference of a circle with radius C E :: degrees in E C F or $e\ \mathrm{C}\ f$: 360.

Or,—

$$\mathrm{E\,F} : 2 \times 3{\cdot}14159 \times \tfrac{3}{5} :: \text{degrees in } \mathrm{E\,C\,F} : 360.$$

It has been often remarked that the size† and form of the eye, and of its chief media, and even their refracting powers, vary sensibly in different individuals, to an extent that would not have been anticipated for an organ whose performances seem to require such a nicety of construction. By a change in focal adaptation, even several of the main optical conditions alter. Besides, in the physiological researches contemplated, it is frequently impossible to make *strictly* accurate observations of apparent size. In every way, it is plain that we cannot depend upon results obtained by the above average elements of calculation as being correct beyond a certain degree of probability. They must only be accepted, *by themselves,* as being an indication of the truth.

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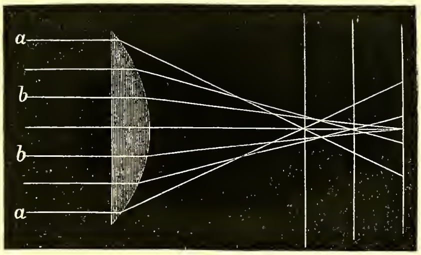
* These *mean* values are gathered from Physiologische Optik, von H. Helmholtz, § 10, Allg. Encyklopädie der Physik, and Beitrag zur Physiologischen Optik, von J. B. Listing (Göttingen, 1845).

† The dimensions of the chambers of the eye, in many instances of both sexes, have also been carefully measured by M. Sappey, *Gazette Méd.*, 1855, Nos. xxvi. and xxvii.

7. Convex surfaces and lenses of uniform density so refract the rays of a pencil of light as to bring those that pass near their edges to a focus sooner than those that pass near their axis,—an effect that is called spherical aberration. Thus, in Fig. 4, the parallel rays *a a* decussate at the near white transverse line, whilst the rays *b b* only meet at the far one. In the eye, not only the greater curvature of the posterior compared with that of the anterior face of the crystalline lens, but the fact of this becoming rarer from its centre to its circumference tends to correct this fault, though perhaps the correction is never perfect.

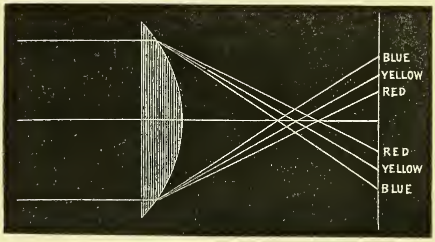
Fig. 4.



8. But, on account of difference in refrangibility of

the differently-coloured rays which constitute white light, this, when refracted, is decomposed into the colours of the solar spectrum—a dispersion of rays that is called chromatic aberration. Thus, in Fig. 5, a parallel pencil of white rays is shown separated into colours, the blue ray being more refracted than the red. Hence, if these rays be received on a screen just before they decussate at the axis of the lens, the blue will be in the middle; if just afterwards, the red. If we look athwart the bridge of the nose at the moon, or carry a finger across the pupil until we see it through a narrow segment of the aperture only, it will seem to be red towards the nose or finger, and violet on the other margin; because the last colour is bent towards the obstructing body most, and by the retinal inversion of images appears as stated. In reflecting the light of the sun into the eye from the head of a pin held close to it, we see a series of coloured concentric rings around a coloured circular area, distinct from the abrupt diffractive rings due to the iris—a perfect solar *spectrum* of the pupillary opening with the most refrangible colours in the middle. Could we bring a divergent or a parallel pencil of rays to a focus sufficiently in advance of the retina for it to spread again over an easily observable space on that surface, the order of the colours would be reversed. It has never

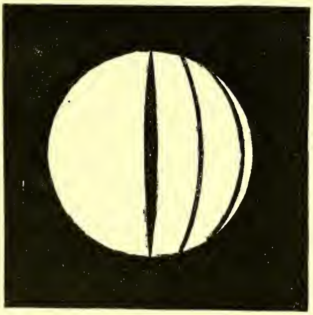
Fig. 5.



been ascertained that there is any mechanism in the eye for obviating chromatic dispersion.

9. If we look through a pinhole at a straight narrow object (as a hair) whilst it is made to pass across the hole a little beyond the card, it will only appear to be straight when its image falls as a diameter to that of the pupil: in every other position it will seem curved with the concavity towards its centre, and the more markedly so the further it retires from it. Dr. Thomas Young* points out that this is owing to the lateral refraction of the ocular convex lenticular system. If the hair be carried across the eye in the same direction within the card, a similar curving of its image may be noticed, produced by the opposite side of the eye. In Fig. 6, the circle is supposed to be a projection of the pupillary aperture by the pencil of rays diverging from the pinhole: the shadow of the straight object is drawn in three different positions.

Fig. 6.



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[*] Bakerian Lecture, 1800,—Phil. Transactions, 1801, pp. 68, 69.

CHAPTER II.

ENTOPTICAL METHODS.

10. The light that enters our eye causes us to see, under certain conditions, a series of objects that exist in the organ itself. An investigation of these conditions is called entoptics.

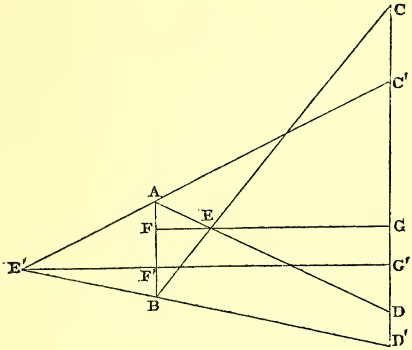
Such apparitions as we allude to arise generally from certain rays being absolutely or comparatively blocked from the course they would otherwise pursue,—or else turned aside by refraction, reflection, or inflection at some object they encounter. But since the pupil is occupied in common by the pencils of rays from *all* visible points, whilst they again separate as they get near the retina, it is only when the phenomena originate far back in the eye that they are discernible in the diffused light of day. Or, to view them in other cases, we must regard a bright space of limited extent.

And to make *precise* observations, we should resort to pencils of rays which do not return to foci upon the retina, so that effects once evolved may not afterwards blend with and obliterate one another; as by using rays diverging from some point external to the eye and within its least focal distance, or rays converging to and then diverging from some point within the globe.

When a portion of the rays of such a pencil find some body in their path, if a simple shadow is not the consequence, some appearance sufficiently indicative of the body's contour to warrant our currently mentioning it as an image of it, will be projected in the line of the shadow. So that, for the geometrical purpose of discovering the seat of the intervening body—a prominent problem in this essay—we may regard the image as a shadow; as also, with certain precautions, for ascertaining the size of the body. Our ideas of the nature of the body must be derived from a more particular examination of the phenomena it yields under different physical conditions.

Draw A B and C D (Fig. 7), any two straight lines parallel to each other; join A D and B C, and through the point E, where the two straight lines thus made intersect each other, draw F E G perpendicular to A B or C D, meeting them in F and G respectively.

Fig. 7.



Again, taking some point E′, on the other side of A B, to that where E is situated, join E′ A and E′ B, and let the straight lines thus made be produced to meet C D, or C D produced, in C′ and D′ respectively. Lastly, draw E′ F′ G′ at right angles to A B and C D, meeting them respectively in F′ and G′.

From similar triangles contained in the figure we have C D : A B :: E C : E B, or :: F G : E F; that is, since E G = F G — E F,

$$\text{C D} = \text{A B}\left(\frac{\text{F G}}{\text{E F}} - 1\right) \quad . \; . \; . \; . \; . \; (a).$$

In like manner, C′ D′ : A B :: E′ C′ : E′ A :: E′ G′ : E′ F′, and therefore,

$$\text{C}' \text{D}' = \text{A B}\left(\frac{\text{F}' \text{G}'}{\text{E}' \text{F}'} + 1\right) \quad . \; . \; . \; . \; . \; (b).$$

11. But, firstly, if we view the figure as representing everything as falling in the plane of the paper, we may take A B to be an object lying in the course of a pencil of rays, which converge to the point E, and C D to be its shadow received, under the conditions implied above, after the rays have passed on divergently from E. In the same way, C′ D′ will be a shadow of A B thrown by a pencil of rays diverging from E′.

And we perceive at a glance, that in the former case the shadow is an inverted image, whilst in the latter it is an erect one; that in either case the length of the shadow varies directly as that of the image. And for a given object the length of the shadow is to its own as their respective distances from the focal point. When the object moves to the focus (E F = 0, or E′ F′ = 0), the shadow is infinite in length; and when to its shadow (F′ G′ = O), both their lengths are equal. But if we assume the object and shadow to have fixed places, whilst the position of the focus alters (that is, F E or F′ E′ alone to vary), the equations (a) and (b) show how the approach of the focus to the object on their respective sides of it augments the shadow: that, for instance, (E F = E′ F′) at equal distances from it, the shadow in the divergent pencil is longer than the other by twice the length of the object. If the focus comes up to the screen on which the shadow is received (E F = F G), there will be no shadow.

Finally, if we know all the terms in either equation, except A B, the length of the object, this may be determined.

12. We may, secondly, regard the same figure as indicating yet other matters. If we imagine a pencil of rays proceeding from left to right to decussate, or pass through a focus at A, and another pencil to do the like at B, C D will represent the distance between the two shadows of any object, E, lying in the divergent portions of the pencils, and C′ D′ that between the two shadows of any object, E′, lying in the convergent portions—that is, if received upon a screen, as implied in the diagram.

Wherefore, in the first case the objects are inverted in position with respect to the foci; in the other, erect. In either case the distance between the two shadows varies as that between the two foci; and that between the two former is to that between the two latter as their respective distances from the object. Hence, too, if the foci, preserving their distance A B, move, whilst the positions of the object and screen remain the same, the separation of the two shadows is greater when the foci approach the object; when A B arrives at the object, the two shadows are infinitely apart. Should the foci be brought up to the screen, the two shadows would be at their distance (A B) from each other. But if we assume the foci to be fixed as well as the screen, whilst the object changes its place (F E and F′ E′ alone to vary), the equations (a) and (b) show how the approach of the object to the foci, on their respective sides, augments the separation of the pair of the shadows; and that if E F = E′ F′, the distance between the pair in the convergent pencil is greater than that between the pair in the divergent by twice that between the foci. If the object touch the screen (E F = F G), the two shadows coalesce. But if E′ F′ = F′ G′, the two shadows are twice as widely sundered as the foci.

Finally, if we know all the terms in equations (a) and (b), except E F or E′ F′, the place of the object, this may be determined.

13. It being proposed to make the principles above explained the fundamental method of exploring our own eyes, we must not forget (6) that the screen, our own retina, is curved, nor that there may be in eccentrical parts of it a certain amount of parallax from the law of vision by normals to it, nor that the rays of light that reach it are bent by ordinary ocular refractions. Insomuch that, in obtaining absolute values from the foregoing proportions, we must not reckon beyond upon more or less approximate results. These circumstances, however, cannot be said to occasion embarrassment; because we shall find no great difficulty in evading or correcting such aberrations. And it will transpire, as

we proceed, that there are no physiological problems of any prominence, open to this mode of treatment, in which comparative results alone are not efficacious.

Let us seek for pencils of rays of the two kinds, which may be conveniently thrown upon our retina.

The diffused light of day, from the sky, clouds, smooth sheet of water, white road, or wall of a house, admitted into the eye through a fine puncture in a thick or black card, gives a good divergent pencil; though the convergent one, in this instance lying in front of the puncture, is not available.

Nevertheless, with light issuing from small luminous discs, we can readily command all such pencils as we need. We may, by means of the head of a pin, or the surface of a convex lens, reflect into the eye, from the sun or a candle-flame, very fine divergent pencils; or by rendering the rays from a small distant flame still more divergent, by allowing them to pass through a concave lens before entering the eye, we may command a very efficient pencil of this kind; or we may use the image of the disc formed in the focus of a lens of short focal length for this purpose. If we look through a convex lens of an inch focal length towards a gas- or lamp-flame, remotely (as at the length of a long room) situated, so that the image may be formed at or near the principal focus of the lens, that there may be yielded a rapidly convergent and therefrom divergent pencil, the eye may receive, to more than half its depth, far enough for all practical purposes, a divergent or convergent pencil at pleasure. By approaching the disc we can introduce the focus deeper into the eye. In a word, we may consider ourselves equipped for the major part of our researches, if we are provided with an object-glass of a microscope of an inch focus. By fitting the tube in which the glass is fixed into another of card-paper, we can slide one within the other, so as to introduce the focus any *measured* distance into the eye.

With beginners, however, the tube may happen to be so held as to occasion the image of the orifice to be mistaken for that of the pupil; so lenses free of tubes should be preferred. For divergent pencils I have often used a Coddington lens of exceedingly short focal length. I have found one or two small lamps with flat wicks very convenient. By looking at the edge of the flame, we have a fine divergent pencil in the *horizontal* direction; and, turning the flame low, we can get one in the *vertical.* For the very nicest observations, I have placed before the lamp a sheet of thick pasteboard, in which a hole had been bored with a gimlet at the level of the flame, so that the light from its surface can only reach the eye through the hole; whilst I have hung a curtain between the eye and the flame in such a manner that even the light thrown by the lamp upon the walls of the room is prevented from being reflected into the eye. In this way we may obtain a *small, bright, round* source of light, which it is very important to have sometimes, especially when we use the convergent pencil.

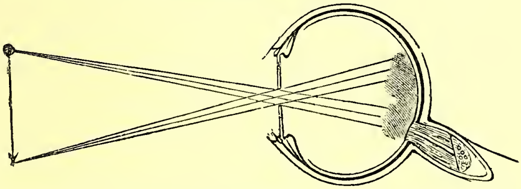
When the illuminating power of the light falling upon the retina from a pencil falls short of that which stimulated it before we commenced our observations, we shall not be able to see well until we have kept the pencil to the eye for about a minute, that the sentients may have time to recover themselves.

In commencing, however, the actual application of the geometrical deductions of 11 and 12, we must take into account that all projections upon the retina will appear inverted; and that thus what has been described as being inverted will *seem* to be erect, and what as erect, inverted.

14. If a single pencil, then, diverge (11) from a point a little in advance of the eye, this point will be the apex, as it were, of a cone of light, the size and shape of whose retinal base will depend upon that of the pupil, of which indeed it will be an erect, and therefore apparently an inverted, luminous image; comprising apparently inverted images of all the objects that intrude upon the cone, in apparently inverted positions with respect to its own centre, and with movements seemingly diametrically opposite to those they really have, if any of them move independently of the eye itself.

Fig. 8.

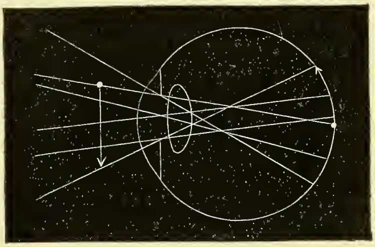
Two divergent pencils projecting the pupil on the retina, the ends of the arrow marking their sources.



If we use the lens, and carry the focal point towards and then into the ocular media, it will arrive at a depth where the divergent pencil will no longer fill the pupil, and therefore no longer project a complete image of the margin of the iris, nor of any of it if the axis of the pencil pass through its centre. Still, so much of this margin, and of whatever else fall in the divergent pencil, will display the inverted effects just adverted to: while whatever have been embraced by the advancing cone of convergent rays will *appear* erect, in their *true* positions with respect to one another, and with the *actual* movements independent of the eye they may happen to have; presenting up to this point a complete inversion of the picture we had of the same things in the divergent pencil. If we still continue to carry the focal point inwards, the convergent pencil will finally fill the pupil and show it erect.

Fig. 9.

Two convergent pencils projecting the pupil on the retina: one is marked by an arrow.



By referring to 11, and interpreting the word *infinite* as applied to an image, as meaning filling the retinal field, or occupying the whole pencil of rays, we may see how the retinal shadows or images of interrupting bodies vary in size, as the focal point falls before, upon, or behind them. Thus, by this means alone, we may immediately observe the order in distance from the retina, iris, or tear, or any known ocular site, in which such bodies occur.

15. There is a point in the axis of the eye which (5) has been called its optic or lenticular centre, which we may regard as most nearly that where the rays from external visible points that hold a *straight* course to their destination all cross each other. Hence, if the focus of the lens we apply to the eye be made to coin-

cide with this point, we may regard its rays as proceeding through the eye *undiverted by ocular refractions.* We are able to observe when the focus impinges on the cornea, and can thence thrust it inwards by $\frac{7}{30}$ths of an inch (6); or can judge when it is about at the optic centre by observing the posterior surface of the crystalline lens (Chap. IV.).

In conceiving in the diagram the screen as a straight line, we virtually represent the retina by its tangent; and we may do this for *small* angles, because in them the lengths of the arc and tangent do not *appreciably* differ from each other. But the optic radius (5) is that of the back of the retina. Wherefore, in every way, speaking generally, when we introduce as far as the optic centre a pair of foci nigh enough together to cast the corresponding points of any pair of shadows we may wish to view near each other, we adopt the best expedient for insuring accuracy in numerical results deduced from the foregoing equations.

In attempting from 11 and 12 calculations as to size and distance, in this manner, we use an instrument which prevents our seeing, with the eye which we are exploring, objects of the external world; but we can note apparent sizes and distances of the images against any surface at an ascertained distance from the eye's optic centre, by aid of the other eye.

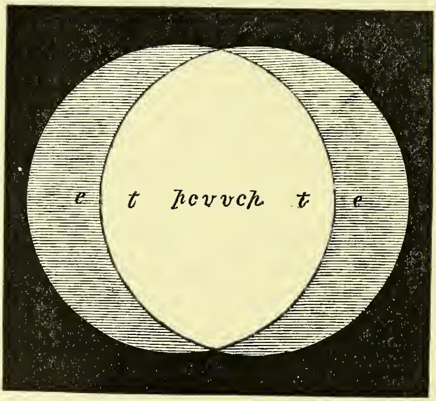
We may mark experimentally in a given case the distance of the focal images of the two discs from the centre of the lens we use, and calculate the separation of these images, as in the instance of the eye (5); or we may employ the usual formula for such a purpose.

16. If we now have recourse to two crossing pencils

(12 and 14) of the pairs of like images projected upon the retina, those images contributed by the right-hand source of divergent rays will be *seen* on the right of their fellows. But when we derive our divergent pencils from the images of a couple of bright discs (14) by means of a lens, these images have respectively changed sides in regard of their discs, so that the projections by the right-hand disc *appear* on the left of their fellows, whilst those rendered by the convergent pencil of the right-hand disc fall, in appearance also, on the right of their fellows.

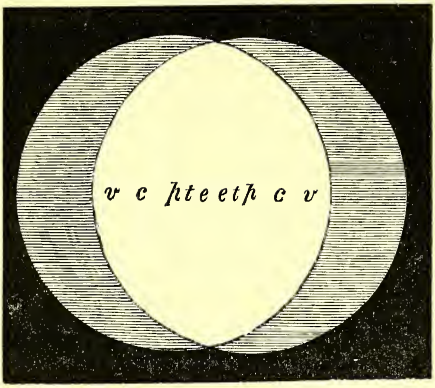
As the principal transparent structures of the eye are an alternation of solid and fluid media, a very rough application of our rules would enable us to observe in which of these media any shadow-throwing body is situated, because those of one kind will be fixed in the eye, whilst the others will float in it; those occurring anteriorly to the conjunctiva, and the iris within the globe being moveable at our pleasure, without the globe itself being disturbed. Thus (Fig. 10), an eyelash (*e*), tear (*t*), iris (*p*, its centre), an object in the crystalline (*c*), and one in the vitreous (*v*), with a couple of diver-

Fig. 10.



gent pencils in front of the eye, would cast pairs of shadows, subtending angles less and less in the order in which their causes are here cited. But when the same bodies (Fig. 11) are immerged in a couple of convergent pencils, the pair of shadows of the eyelash subtend the least angle, and, in order, the others greater and greater angles. This sort of inversion is a striking event; so that the mere passing of the imaginary line that joins the two foci from before backwards, tells us at once which of two ocular bodies is deeper.

FIG. 11.



17. For the clearer understanding of a modification of the mode of investigation by two pencils, of practical moment, we may remark, that could we look with the same eye, and at the same instant, towards a distant small luminous disc, through two side-by-side convex lenses with parallel axes, the right-hand lens would fling its image of the disc to the right of that of the other, and all the fellow shadows thrown in the two divergent pencils would be seen in just such mutual relation as happens in the case of light from two punctures or two lucid points; wherefore the convergent pencils from the lenses would so project the objects

lying in them, that the images caused by the right-hand lens would appear on the left of their fellows.

Hence, if we gaze through a *single* puncture in a card at the apex of some terrestrial object visible against the sky, or a fixed spot of any luminous surface, or gaze straight forward towards a lucid disc through a lens, and move the card or lens about across the optic axis perpendicularly to it—*taking care with the lens to keep its axis always parallel to itself or to the optic*—we may affirm that a dark spot, owing to a blind place in the retina, or some thin object resting flat upon the visual sentient points, will not appear to move, and that the shadows of objects will seem to travel *in the same direction* as the card or lens, with a perpetually increasing velocity, as they are situated nearer to the point of divergence; whilst whatever objects are encountered by the convergent pencil will seem to make excursions in the *adverse* direction to what the lens does, with a swiftness continually decreasing as the object is further in advance of the point of convergence. We have merely to turn the lens upon its axis to rotate its contents so as to distinguish them from retinal objects.

True it is that we cannot see the remote disc through the lens. But in moving it *as advised*, the nearly parallel rays from the disc must keep passing every point in the substance of the lens in the same style, or all such rays for a given point in the glass would fall upon the cornea parallel to one another, and thus upon the same retinal point. So that the extremity of a short tube in which a lens is set, seen through or beyond the latter, or any of the numerous obstacles to the free passage of light, so common in glass lenses, will, practically, seem to abide in their original sites, however widely the lens, within the limits of the pupillary opening, be borne across the optic axis, yielding *fixed points* for our regard to rest upon, of the most commodious sort. In other words, in these cross-excursions, images due to the lens and those due to the retina suffer no displacement; whilst the rate of movement augments as the object imaged approaches the focal point; the movement being evinced in a retrograde manner with respect to that of the lens for objects between it and the focal point, and with that of the lens for those between the focal point and the retina. Thus, in a case in which divergent pencils (especially if from points anterior to the eye, as in the earlier entoptical methods) yielding parallaxes in the same direction, would produce no distinguishable difference, when there is room enough between two bodies situated a little deeper one than the other in the eye, for a focal point to be carried transversely between them, their images appear to *fly asunder*. Just as when the line joining two foci derived from two lights is placed between the objects, this great opposite deflection may be witnessed by noticing on which side that image of each pair lies that vanishes when we shut off one light by the hand.

18. We may, of course, as an equivalent, rotate the eye, so as to sweep the cornea across the fixed axis of the pencils.

In such case, the shadows of the objects falling within the pencils will slide over the retina with more quickness as they are nearer the focal point; those in the divergent pencil sliding in the same and those in the convergent in the contrary direction to that taken by the anterior extremity of the eye's axis. Or those in the former *appear* to do so in the contrary, those in the latter in the same.

This mode of observation is scarcely applicable to bodies which may change their places in the ocular media; for fixed ones it does very well. If we look through a punctured card, our field of view, or the luminous aperture of the iris, will *seem* to recede less and more respectively than objects before and behind its plane. Therefore, speaking relatively to this, those may be said to move negatively, and these positively. Listing,* who examines the cornea and crystalline lens by this artifice, thus expresses this fact: "The relative entoptical parallax is null for objects in the plane of the pupil, positive for objects behind, and negative for objects before the pupillary plane. Its magnitude is nearly proportional to the movement of the visual point and the distance of the object from the plane of the diaphragm."

Donders holds a couple of punctures, 1½ *Mm* asunder, close to the eye, and assumes that the distance of an object in the ocular media from the retina bears the same ratio to that of the iris as the apparent separations of their respective shadows bear to each other.† This is another shape of the formula just noticed. A glance at Fig. 8 will make it evident that, with lines *diverging* from two points without the eye, independently of ocular refractions, the two similar triangles imagined only exist approximately. The refractions are usually considerable for rays passing near the margin of the pupil.

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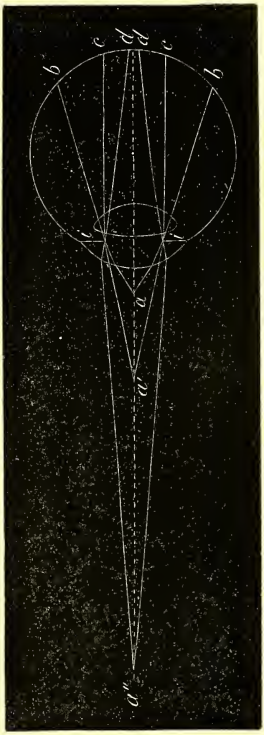
* Beitrag z. Physiol. Optik. § 43.

† As cited in Allg. Encyk. d. Phys. § 162.

19. There is a point about a half-inch in front of the *mean* eye on its axis, which is called its anterior focus, and it is such that rays of a pencil of light diverging thence would, on the supposition of the vitreous being homogeneous, pass through this humour parallel to one another. In Fig. 12, a' is the point, and the lines a' *i c* show the courses of the rays that touch the iris through the eye. The apparent sizes of objects met with by the parallel rays are equal to the actual. When two such approximate pencils cross each other from a couple of punctures held before the eye, the separations of the two shadows of the bodies are as their respective distances from the retina. Listing, followed by Doncan, measured the sizes of certain entoptical bodies in this way.*

FIG. 12.



If *a*, in the Figure, be a divergent point nearer to the cornea than a', the rays *i b* from it will be deprived of some of their divergence by ocular refractions; and though they will still throw shadows of entoptical objects embraced by them larger than their sections, these will be reduced.

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* In completing my exposition of entoptical methods I have cited the names of three writers in connexion with those they practised, but I refrain here from distinguishing any as originators. I shal

If a'' be further removed than a', but within the least focal length of the eye, the rays $i\ d$ from it, though they only tend to meet behind the retina, will be rendered convergent by ocular refractions, and the shadows will be less than the sections, instead of larger, as would otherwise have happened.

In the same manner, when, by aid of a convex lens, we carry a convergent pencil into the eye, this will always shorten the convergence. This effect is so decided, that did we wish to examine the back of the vitreous humour with such a pencil issuing in a divergent one, we should, even for the longest-sighted eye, be obliged to resort to a lens of many inches focal length. But we have little motive for using such pencils in that region.

20. Yet, when we have thus provided ourselves with devices for determining the localities, sectional shapes, and sizes of the bodies connected with the visual organs which obtrude themselves upon our sight, we have not exhausted our means of research: because the form and refractive power of a transparent body may appreciably influence the features of its image; and inflection of light occurs both at the edges of these and of opaque bodies; whilst all the bodies may reflect light. These different phenomena may happen more or less separately or mixed, may be distinct in their character, or may so far simulate another sort of phenomena as to make it difficult to distinguish them. But here, too, it will transpire that the use of the two kinds of pencils is

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have, by-and-by, to speak of others, and shall endeavour at the end of Chap. V to settle who are entitled to be considered as contributors in these studies.

of much greater efficacy than that of the divergent only. It will often be more convenient to take the effects here alluded to into consideration in our analysis of the actual phenomena, since we shall then be aided in our interpretations by comparing one with another. Nevertheless, it may not be amiss to premise a few words on a special topic or two claiming our attention in this study.

A convex lens in a rarer medium than its own, as that in Fig. 4, in gathering parallel rays to a focal spot, illuminates it at the expense of a deep concentric ring as broad as the lens itself, which is rendered dark. Then the rays pass on, causing the ring to become narrower, until, at a distance as far from the focus to the right as this is from the lens, the equable illumination is restored, and the rays received on a screen show no shadow: that is, supposing that the pencil of rays *a a*, penetrating the lens, is merely a portion of a larger one whose rays, passing by the circumference of the lens, directly impinge upon the screen. But, beyond this to the right, the rays which have traversed the lens extend over an area larger than its surface, of which we have therefore a shady image with an illuminated annular border.

This simple illustration will make it easy to perceive that when a partial refraction occurs within the eye, we may, by changing the divergent for a convergent pencil, get an inversion of shade and light. We have thus *ready* criteria of the general form and refractive quality of the cause of such a partial refraction. Certain entoptical globules can thus be proved to be transparent refracting bodies. I dare say it might be possible, by observing the extent of the illuminated border round a dark image in a convergent pencil, or by also observing the distribution of light in an image of equal size projected by the divergent pencil, to compare the refractive power of such a globule with that of the medium in which it resides,—that is, to determine even its refractive index. Such inquiries, however, must be left to the curious. It is not unlikely they might serve to elucidate physiological optics in some particulars: but for our aims there are others which are much more pressing.

21. We notice, then, that the shadow of the orifice of a tube in which a lens is screwed, as seen on the distal side of the glass towards a round lucid disc, shows a series of concentric circles, or alternations of bright and dark *external* fringes, from inflexion of light at the edge of the tube; and that like external fringes surround the shadows of all the foreign particles that ostensibly stud the glass. In addition to which, if the body be narrow, the very middle of its shadow is illuminated from inflection at its sides, even though there may be no other *internal* fringes strong enough to be thus visible; the central luminosity in the shadow of a small round particle being a round area of about the same brightness as the average light yielded by the lens—facts in accordance with ascertained laws of light. If we use an elongated disc, as a candle-flame, these effects must necessarily be best seen in objects that are parallel to the flame's length. Inflective phenomena in the convergent and divergent pencils resemble each other.

In the eye, also, there is much manifestation of the phenomena of inflection; but their laws, though of great interest in these researches, are too various to be detailed here.* They undoubtedly might be used for determining the sizes of entoptical bodies, the place of the focal point of a pencil of rays in relation to the body and the retina, &c.: even in the case of transparent bodies in the ocular media, which also diffract light, such effects might be disentangled from the refractive. The following hints, as a guide in our practical investigations, are all that can be introduced here.

When a body in a divergent pencil is close to the screen (retina) that receives the shadow, there are no inflective fringes internal or external. When the body retires far enough for fringes to appear, they at first (especially the external ones) consist of very sharply defined lines. These get less so and wider as it retires further.

In a word, both in a divergent and convergent pencil the fringes *external* to the proper shadow of the body are wider, though less abruptly separated, as it is nearer the focal or decussating point; and this by a hyperbolic law by which the increase exceeds the proportionate increase of the body's shadow by such approach, spoken of in 10.

In a body at a given distance from the retina, the fringes become finer and more distinct in a divergent pencil by carrying the radiant away from the eye towards the least focal distance of the organ, and in a convergent one by carrying the focal point towards the back of the eye.

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* It will be necessary for those who wish to make a practical application of Entoptics to have a general idea of the laws of inflection or diffraction of light. A popular explanation may be found in Brewster's Optics; or Natural Philosophy, by Dr. G. Bird and Mr. Brooke; one of Churchill's manuals.

Provided we obtain a convergent pencil from a very small radiant, an opaque body with shadows of equal sizes in the two sorts of pencils will display like fringes —the two shadows throughout will be alike, which does not happen in the case of a transparent body.

In the case of an opaque globular body, a broader dark ring is apparent, marking the limits of the internal fringes or of the true shadow of the body. This ring itself, no doubt, involves many subtle brighter and darker ones which the retina is unable to see. Some such rings may be seen in exceedingly bright and minute pencils of divergent light. When we attempt a measurement of the diameter of the body, we assume that this ring indicates the true shadow. But an irregularity of outline in the body's section might, by interference of light, cause the outer circumference of the ring to be unduly expanded or contracted, and thus we might be led into some error as to the breadth of the proper shadow. In the example of transparent bodies we are still more liable to such a mistake, because the rays of light passing by and through them interfere with each other, whilst refraction itself alters the breadth of the shadow. Our greatest safeguard is to measure these shadows in both sorts of pencils: we can also observe the deviations from refraction by looking at the distribution of lighter and greyer parts of the image in each pencil, and thus correct the result by our judgment. But I repeat the caution, that we must not lay too much stress upon our ability to measure these bodies with much nicety.

22. Phenomena of interference, by inflection of white light, are attended with manifestation of colour ; and, as

Sir D. Brewster affirms, by careful scrutiny we may discern inflective colours from ocular objects—we certainly may refractive. But the appearances we are to investigate are so immersed in a pervading coloration, the offspring of ocular chromatic dispersion, that no other kind merits much attention. Of course, we may get chromatic dispersion from the glass lens we apply to the eye. And the refractive curvature of images of long bodies (9) seen eccentrically through lenses may be witnessed as caused by small accidental lenses met with in or upon the eye, when their effects will be conjoined with those of similar kind by the eye.

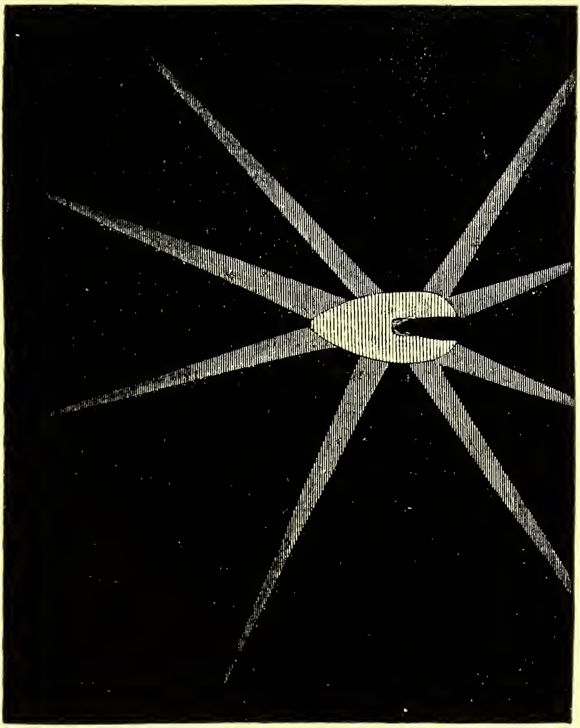
CHAPTER III.

APPARITIONS FROM EYELASHES, EYELIDS, AND CONJUNCTIVAL FLUIDS.

23. In applying the principles just deduced, for the purpose of evolving from each other the accidental phenomena of vision, let us first turn our attention to those contributed by the structures that shelter the eye. Not to particularize the effects produced by the hairs of the eyebrows, which act like the eyelashes when the brows are gathered, or when we turn the eye towards them, the eyelashes, unless the lids are widely opened, reflect (13) pencils of light into the pupil, more or less completely filling it. In Fig. 13, a few such pencils radiate from a flame as they obtrude themselves upon us at night. Against direct sunlight, such pencils manifest the chromatic dispersion with the entoptical contents of the eye. By passing a loose hair from the head across the eye, we can at once detect the way in which these pencils arise. Before it gets between the pupil and the flame, it will reflect a pupil-full of rays into the eyes, which will cause it to be seen dilated in the shape of a short beam *detached* from the flame. When it gets between them, rays will be reflected very obliquely under opposite margins of the pupil, and a long beam will shoot on either

side of the flame in a straight line; of which kind are most of those in the figure, being those that most attract attention. (Refer to article 31.)

Fig. 13.



The eyelashes, too, when immersed in a divergent or convergent pencil, exhibit internal and external diffractive fringes (21), as shown in Fig. 14.* If an eyelash happen to rest between the eye and a luminous disc—say a candle-flame—so as to be parallel to its axis, we see a series of lighter and darker spaces, as in Fig. 15, which are the representatives of the external fringes of Fig. 14: the brighter spaces are plainly imperfect images of the flame. There is also reflected light thrown along the path of the row of fringes: when we curtail this light by partially closing the lids, the diffractive effects are shown more distinctly Colours are to be discerned along it, some of which must spring from chromatic dispersion in the eye; whilst the same colours are here and there repeated in patches, and must be ascribed to diffractive interference.

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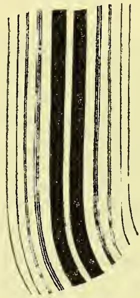
* Look at Fig. 25: just as the centre of the stout black ring there is less bright than the lucid external fringes, so should the bisecting line in this figure be less bright than the lateral lucid fringes.

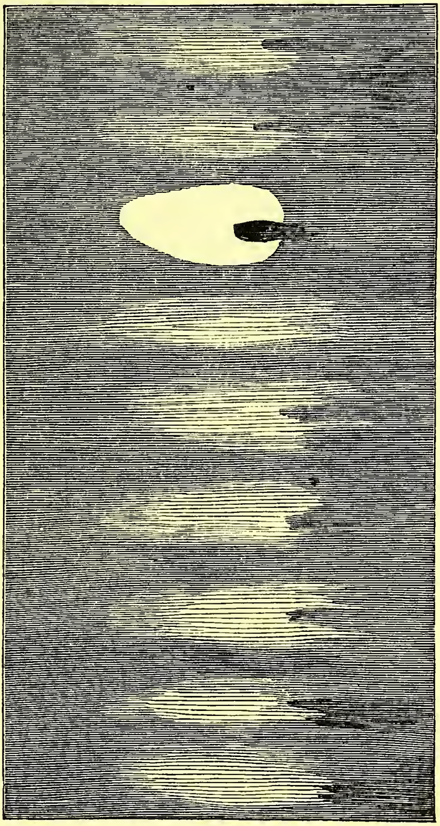
Fig. 14.



24. Since (4) greater refractions occur at the eye's surface than within it, slight inequalities there might be expected to betray themselves to our observations; yet the lubricating fluids are frequently so equably diffused over the conjunctiva, that our pencils almost fail to disclose them; but, with fitting examples present, we may see with divergent rays both illuminated and opaque pictures of drops of fluid—a contrariety announcing a difference in form, both drops being transparent, to the effect that the former are elevated and the latter depressed in the middle. Thus the convex tear (the more frequent kind) brightens its image and gives shade to its areola, by abstracting from the divergency of the rays that penetrate it; whilst in the other case the areola is brightened at the expense of

the image. When these drops are immersed in a convergent pencil, the illuminated image becomes dark, and the darkened image bright; the convex tear, by increasing the convergency of the rays that pass through it, causes them to diverge sooner than the

FIG. 15.



mass of rays; whilst in the other case they do not meet so early. (21.)

Fig. 16.

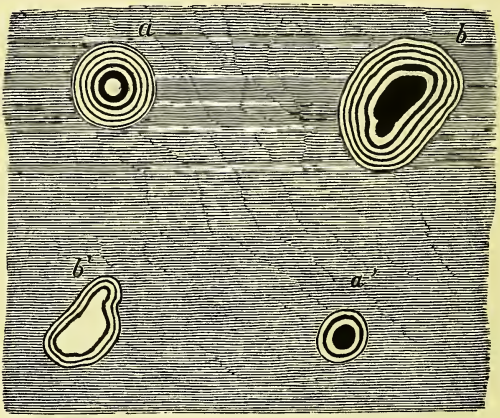


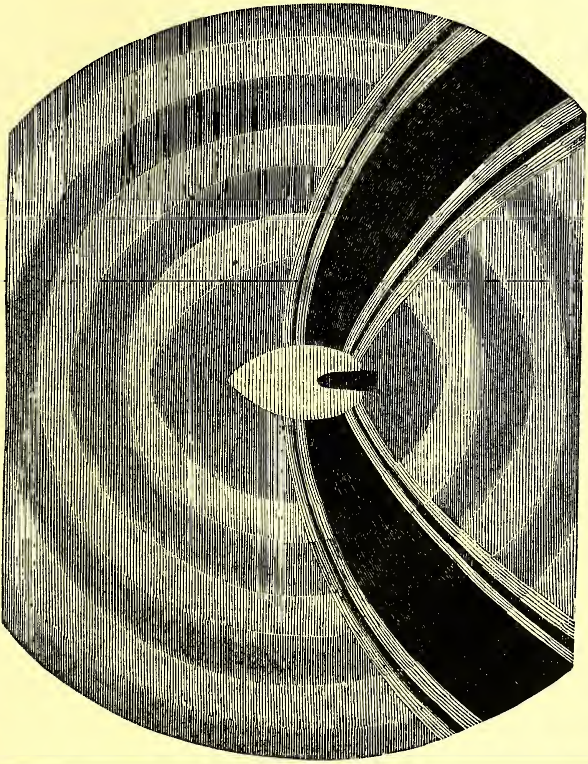
Fig. 16.—*a* and *b* are two drops of conjunctival fluid in a divergent, *a′* and *b′* the same in a convergent, pencil.

These little lenses, if we look at a candle-flame through a lens, tend to form erect or inverted images of it, according to their own form. They average from $\frac{1}{100}$th to $\frac{1}{200}$th of an inch in diameter (15).

The rays passing by and through these tears interfere with each other, so that a series of fringes surround the light and dark images; four, five, or more alternations may be counted, or in a flattish tear in a fine divergent pencil, perhaps twenty exquisitively fine ones. The illuminated middles of the images of the tears are broader and brighter for the size of the object than in the example of an opaque body, whose image preserves a like middle both in divergent and convergent rays (21).

These tears (as I, for brevity, call all drops of fluid on the eye) display round a candle-flame a series of wide brighter and darker rings (Fig. 17), and in this common way obtrude upon us phenomena like those described above. A convex tear by the divergent pencil, formed by it a little within the cornea, manifests beautifully the contents of the vitreous humour, and chromatic dispersion either from its own refrac-

Fig. 17.



tions or the eye's. A concave tear may yield an immediate divergent pencil, and thus betray the contents of the crystalline lens and a portion of the iris, as well as more posterior objects. A straight eyelash seen through a tear against a flame placed at the other end of the room, seems curved, if the rays that show it fall laterally to the axis of the tear, owing (9) to its lateral refraction; in a manner varying with the forms of the little lens. In Fig. 17, in which the fringes of a round tear have been cut off at the sides to save space, one aspect of the hair's shadow has been introduced. Such a shadow, as the head is made to move to and fro or up and down, that the hair may oscillate between the flame and vertex of the tear, exhibits nimble inversions of its curve. It will often carry additional fringes, the whole being spread out from the flame, in a straight line, like a couple of fans when the hair is in front of the vertex; and when it deviates to either side, bending from its middle, until the two fringed limbs of the shadow meet. This shadow is very likely to present, at its narrower part especially, a bisecting lucid band after the type of the middle line in Fig. 14.

When the upper eyelid is lifted, we observe to follow it (upwards in a convergent pencil, and downwards in a divergent) frequently a series of drops. Listing noticed that the drops climbed after the upper lid, and ascribed it to its attraction.

If the eyelids be kept closed awhile, the marks of the Meibomian glands, and of other inequalities of the lids, will persist in the conjunctiva for a time; and if kept closed by even a gentle pressure of the finger, such inequalities, with those of the finger, may remain impressed for many minutes. Fig. 18 may give some rough idea of this effect, as viewed in either a divergent or convergent pencil; the distribution of darker and brighter patches, as far as they arise from unequal refraction—and not from diffraction—being approximately that of brighter and darker in the other. By the principles of 11 and 12, we may determine the seat of these "curdled" phenomena (to use the language of Dr. T. Young), and, should we desire to do so, the kind of superficial irregularities that produce them. We may find it convenient sometimes to purposely make a slight conjunctival impression as a ready way of deciding, by difference of entoptical parallax, whether certain opacities are at the eye's surface or in the crystalline lens.

FIG. 18.

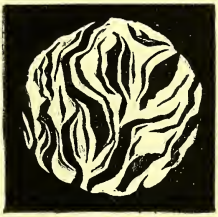
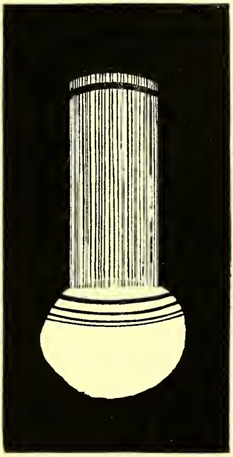


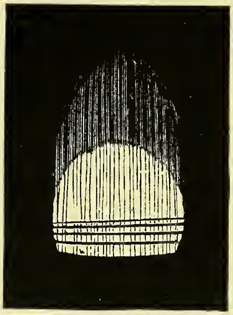
FIG. 19.



25. Furthermore, whilst employing the divergent pencil, let an eyelid encroach upon it, and we observe along its shadow—which is disposed to bend (9) its middle *unduly* from the centre of the pupil's image, and approaches from the opposite direction—a series of fringes. Fig. 19 shows these for the under lid. In a convergent pencil (see Fig. 20) for the same lid, the fringes are scarcely distinguishable from those in the other. But if, with a divergent pencil, we

quickly withdraw a lid which had rested awhile in one place, beyond the dark band which indicates the hollow in the fluid left by the retreating lid, a luminous band, bearing fringes, remains behind, longer than a luminous impression would be extant upon the retina, from the instant of such withdrawal. In the convergent pencil there is a modification of this by substitution of a dark for the luminous band. We are aware that a little bar of fluid, as it were a prism, vertically concave in front from the attraction of the eye and lid, must gather along the angle between them. Hence, it is plain that the image of this prism is not definitely projected in either pencil on the retina next that of the lid, where it would be coincident with the inflective fringes caused by the latter. Nevertheless, it has been shown that we may entoptically detect the presence of a linear accumulation of fluid along the lid by briskly withdrawing it; and that the external fringes belong to the fluid, and not to the lid.

Fig. 20.



Again, we observe that in the divergent pencil (Fig. 19) we have not a dark shadow of the lid; but a long stream of light shoots upwards, obviously broken into linear rays by the intervention of eyelashes, (those show more with the upper lid,) and perhaps by Meibomian glands; whilst in the convergent pencil (Fig. 20) we have a true shadow of the lid, the stream of rays still springing *upwards*, commencing at it, and, if it advance sufficiently over the cornea, traversing the image of the pupil and passing far beyond its margin.

FIG. 21.

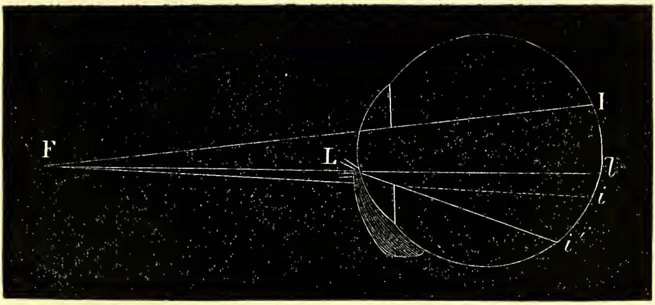
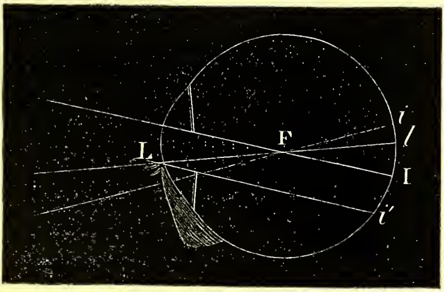


FIG. 22.



In Figs. 21 and 22, let, in section along the optic axis, F be respectively a radiant point without and a focal point within the eye; I *i* the image of the pupil in the divergent or convergent pencil that fills it. Now let the under lid intrude upon the pencil, as at L: and *l* found by drawing a straight line to the retina through F and L will be the place of its shadow. Draw from L a straight line touching the iris and meeting the retina in *i′*.

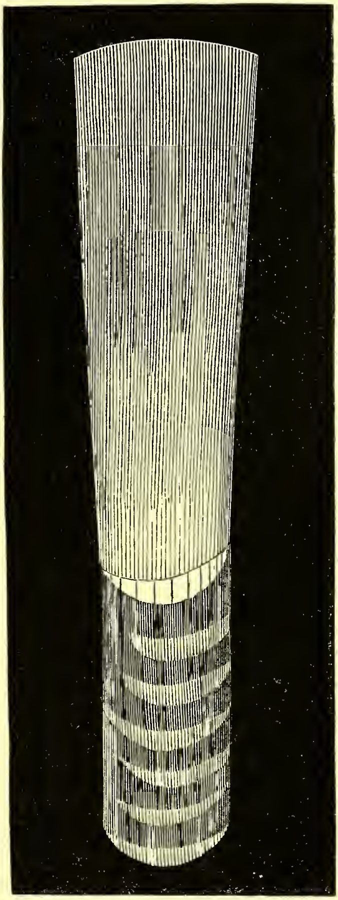
Reading off the retinal pictures from these two figures, in an inverted order to describe things as they appear, we have in Fig. 21 the pupillary aperture with lid covering the site of the under (apparent upper) part of the border of the pupil, which shows itself remotely above (*i′*) its proper place. In Fig. 22, we have the lid covering the real and apparent under part of the margin of the pupil, which shows itself, instead, above even the upper part.

A glance at Figs. 19 and 20 will satisfy us that these statements correspond respectively precisely to what we see displayed in them. The inflective fringes of the iris are indicated in them, and may easily be observed, provided the lid does not protrude itself so much over the pupil that the rays bent away by the fluid resting on it cannot touch the iris.

We thus find that the prisms of fluid along the lids not only abolish the refractive action of the cornea, but even, by presenting a concave instead of a convex surface anteriorly, disperse the rays of light that penetrate them, in the manner shown, over a considerable space, stretching towards the terminal border of the retina. It is the illuminated space that is the sole entoptical image of the prism.

Such phenomena are salient when we blink with the naked eye towards a candle-flame; for it is to the fluid bars along the lids that are due the upward and downward streams of light that issue from luminous discs when the lower and upper lids advance upon the cornea. If, still using the under lid as an example, this be held horizontal, and we bend backwards the head until the lid become a chord to the pupil, the stream of light will spread upwards from the flame like a slightly-opened fan, (Fig. 23 gives a stream a little fan-like, but hardly enough so for this description,) which will manifest the *fringed* edge of the iris, and strongly the colours of the rainbow, the most refrangible along its middle, and the least at its edges. If the hand be passed across the eye, the beam disappears from the opposite side, proving that the rays do not decussate before reaching the retina: hence the order of the colours must be attributed to the fluid bar; and they declare it concave also in its longitudinal direction; no doubt by the accumulation of the free fluids into either canthus of the lids. If the head be bent from side to side, the level of these fluids will be disturbed, and the edges of the coloured fan will approach and pass each other.

Fig. 23.



Hence, too, the beams from the borders of the lids diverge from the cornea, and such entoptical objects as fall in their path are clearly imaged; fibres in the front of the vitreous humour being rendered very large and distinct.

In Fig. 23, we see delineated the stream that sprouts upwards from a crescent moon, when the lower lid intrudes upon the pupil, whilst a number of imperfect crescents with dark intervals prolong it downwards, ending in one which very nearly simulates the original. This is nothing but a row of diffractive fringes formed like those in Fig. 19.

Besides these striking appearances from refraction and diffraction, there are also beams of light, though comparatively faint, *reflected* from the edges of the lids into the eye, when we rest it upon a distant lucid disc. The reflected beam being thrown *from* the lid, grazes, if I may so speak, the margin of the iris which lies under the other lid and falls upon the retina on that side of the disc's image formed thereon. Hence, it is seen detached from the refracted one we have dwelt upon, on the other side of the disc to that which this proceeds from, and perhaps (when the lid hides but little of the cornea) not joined unto the disc, but only pointing at it. Thus, when we wink with both lids invading the cornea, the reflective beam of one lid is coincident with the refractive one of the other; the four beams constituting one long vertical beam.

If we carry, from the lid, the back of a knife over, whilst the blade is perpendicular to the cornea, without touching it, with the candle so placed that the knife reflects a beam of light into the eye, we have only now to let the back come in contact with the cornea, in order for a fluid bar to form on the blade which calls forth just such refractive beams and inflective fringes as we have found the lids to call forth.

26. By nearly closing the lids, we may get in the

diffused light of day, or from the ground-glass globe of a lamp, a divergent pencil through the small aperture thus produced, all other light except such as may penetrate the lids being excluded; by which we may examine the entoptical contents of the eye, and easily distinguish those of the crystalline lens from superficial ones: with direct sun-light, the entoptical bodies being lavishly dressed in fringes. In doing this against light from a limited disc, we must remember that the fluids compressed between the lids form independent pencils, and that, at least, some of the reflective or refractive pencils described will be present. Thus more than one image of entoptical objects will be projected: and, indeed, in any sort of light this is liable to occur, so that this mode of survey is more fitted for viewing than for counting such objects.

Microscopists trace a network of nerves in the cornea; but these refract so nearly like that substance, or are so fine, that they cannot be discerned entoptically at such a distance from the retina. In the sound eye neither the conjunctiva nor the cornea seems to *contain* any bodies to transmit shadows distinguishable from irregularities on the surface and the fluids thereon, nor can anything be found in the aqueous humour.

In his very elaborate and very original Bakerian Lecture, "On the Mechanism of the Eye" for 1800 (Phil. Trans. 1801, p. 82), Dr. T. Young appends the following apology:—"I beg leave to correct here an observation in my former paper relative to the faint lateral radiations from the margin of the iris. I find, on further examination, that they are occasioned by reflections from the eyelashes." And since he further leaves uncorrected a mistake in that paper which ascribes to *reflection* at the lids the strong beams that arise by their infringement upon the pupillary opening, we may presume that this sort of phenomena had not been effectually studied up to that time: yet he clearly pointed out the reason why the fluids on the conjunctiva become visible in light issuing from "lucid" points, and figures an impression persisting on the conjunctiva after pressure applied through the lids. He discriminated superficial from deeper ocular impediments to vision by their transitory character and their being removable on winking the lids, yet not by an entoptical principle.

Brewster, in his entoptical paper on *Muscæ Volitantes* read before the Royal Society of Edinburgh in 1843, merely passingly mentions the visibility of the conjunctival fluids.

In my earliest entoptical essay, in 1845, I wrote as follows:—

"I shall first make a few remarks on obstructions to light anterior to the conjunctiva.

"The eyelash sometimes interferes" (that is, in a divergent pencil from a punctured card) "with the field of view. It seems to be the under, and is, therefore, really the upper; and this interference may be avoided by pulling up the brow, or by holding back the head and looking in a downward direction. Tears, like drops of water on a window, or other fluid on the conjunctiva, like clouds horizontally shaded, parallel to the lids and caused by them, irregularly or regularly waved or streaked, or even blotted very distinctly, appear with the card, though by no means visible without it. The nature of these fluids, by which the shadows are thrown, may easily be recognized either by the optical laws laid down above, or by their disturbance on moving the lids." *

In Listing's entoptical paper, published more lately in the same year,† there are five engravings devoted to these appearances, and he treats several of them with more precision than previous writers had done. His observations are all made with a divergent pencil. The eyelashes and eyelids are shown (in the only one of the engravings that can be considered new at that time) in this pencil, with lucid borders (like those in Fig. 45 from reflection), where we see inflective fringes, but no such fringes are indicated. "The figure," says he, "places the obtruding eyelashes of the upper eyelid in the circle of expansion (Zerstreuungskreise,—that is, pupillary image). The under part of the field of view is darkened by the lowered eyelid. The stripes of light that extend downwards upon this shadowy space from between adjacent eyelashes arise from the dispersion of light at the tear-fluid, whose surface is strongly concave-shaped through capillary attraction, and which lies along the rim of the eyelid. These stripes of light, with an intense source of light, shoot downwards, very strongly marked, and with considerable elongation; in sun-light, along with irregular but brilliant effects of dispersion and interference." I have quoted all he writes about the fluid prism along the lids whose presence he detected. He tells us, too, that drops of fluid on the conjunctiva are elevated by capillary attraction round lumps of mucus, or foreign corpuscles, and how, as little lenses, they yield inverted images of discs of light at which we look.

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* Points in the Physiology and Diseases of the Eye, London Medical Gazette, vol. xxxvi., p. 66.

† Beitrag z. Physiol. Optik, ss. 32—41.

Helmholtz, in his article on Physiological Optics,* extracts Listing's observations without improving upon them. He records, however, that Meyer (1853)† has written on the stripes of light issuing from the tear-prism on the lids, without giving any hint of the purport of the communication, and allowing it to be inferred that he had not himself read it. I think it right to repeat Helmholtz's reference, though I have not the means, from want of access to the paper, of knowing whether it contain anything deserving quotation. If it treats of the beams of light that shoot upwards and downwards when we wink towards a candle-flame, I may mention that I had accurately explained these, in ignorance of Listing's writings, in 1848.‡ Hence, unless this historical sketch be defective, several interesting phenomena have been left to be first described and figured by the present writer.§

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* Op. cit.

† Paggendorff's Ann., lxxxiv. 518.

‡ London Med. Gazette, April 21.

§ See, too, his Ocular Spectres, &c., 1856; and Med. Chir. Review, 1859, Entoptics, p. 473—8.

CHAPTER IV.

IRIS AND CRYSTALLINE LENS VIEWED ENTOPTICALLY.

27. At due depth from the tears (6) we encounter, in our entoptical researches, the iris; and in a pencil of rays, whose focal point does not fall too near to the pupil, whether it be divergent or convergent, we observe a series of inflective fringes, as in Fig. 24, belonging to it; in light from a brilliant point, in advance of the eye, even closing in rings upon the very centre of the pupil's image. In such case, if the pupil's retinal image be very small, these fringes may not be the *external* ones of the border of the iris, but may be caused by the interference of rays from different parts of the circumference of the *small* opening. We may judge between these phenomena by passing a finger near the eye across the pencil; in which case the external ones will vanish with the *apparent* opposite side of the pupil: whereas, in the other case, more or less of the fringes lying on the *apparent* same side will fade away.

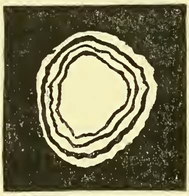

Fig. 24.

If the direct light of the sun be admitted into the eye through a fine puncture, a number of contracting and dilating subtile fringes will play about it, which are caused by it, and may be detected as being so by the expedient just adduced, or by turning the card in which the puncture is made about the axis of the hole, when there will probably be sufficient inequalities in the circumference of the puncture to occasion the general aspect of the fringes to rotate also. Again, by shutting and opening the other eye, the fringes of the iris will be seen to conform themselves to the expanding and contracting pupil. To obviate error, it is best, in studying the fringes of the iris, to use light reflected from a polished point, and not such as is transmitted from hole or lens.

With me, as with others, the entoptical image of the pupil is not circular. I find it of an oval figure, rather, whose axis is vertical, and somewhat differing for my two eyes.

28. In my left eye, commencing behind but very near the iris, and ranging through a depth fully equal to that of the crystalline lens, I meet with many opaque bodies of irregular outline, fixed in the globe. They are evidently scattered through the substance of the lens. The lens of my right eye is much freer from such objects; but, on the other hand, it is more remarkable for displaying several larger objects which are near its posterior face. Also, there are in either eye a few discs of a higher refracting power than the general substance of the lens. If (speaking in terms of an inch) I introduce (6 and 14) a pair of foci $\frac{1}{180}$ apart as far as the optic centre, so that in the convergent pencils the shadows of a tear ($\frac{7}{30}$ from the said centre) are *retinally*

$\frac{1}{50}$ apart, and those of the iris ($\frac{17}{180}$ from said centre) $\frac{1}{25}$, the large objects appear in the divergent pencils with shadows showing not more than a retinal separation of their centres of $\frac{1}{15}$, which places them as far back from the iris as the posterior vertex of the lens, which should be $\frac{2}{45}$ from the optic centre. Two of these objects have real diameters of $\frac{1}{350}$ and $\frac{1}{400}$. They may be masses of cholesterine or fat, such as the microscope has encountered in the crystalline, and may have some connexion with the capsule of the lens. The smaller opaque bodies may be earthy particles. They seem to undergo no material change. I have, from their salient position at the edge of the pupil, been acquainted with two of the refracting specks for twenty-four years, and with the rest for several.

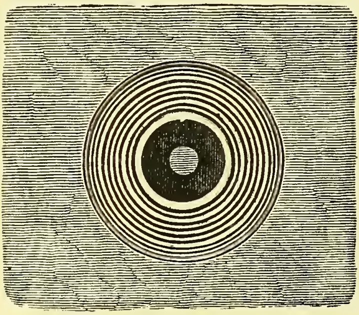

Fig. 25.

In Fig. 25 is shown a shadow of a large lenticular opaque body, in a pencil from a brilliant point just in front of the cornea. There are many fringes, with a central illumination (20) of the same intensity as the ground light. But it does not affect to indicate, what keen attention convinces me of, that even the whole wide black ring is, in fact, constituted of subtile internal fringes which evolve colours, some of which are just strong enough for the retina to realize. In a convergent pencil a shadow of precisely the same character is met with, except that hardly so many external fringes can be obtained in this way.

With the finest pencils of either kind, comparatively very minute opaque bodies reveal themselves in the lenticular substance by shadows, each within its rings, and with such a central lucidity as has been described. Fig. 26, omitting the central brightness, gives an idea of such a shadow by the side of the larger one. In Fig. 27 I have attempted to convey some idea of the features of my right lens, as projected upon the retina in a divergent pencil, as far as it is affected by unequal refractions at its (*many*) surfaces, and opaque and transparent specks in it, and a curved linear transparent object; but the refractive fringes, which show themselves more or less round most of the specks, are dispensed with. In Fig. 28 are presented the shades that the transparent objects yield in a convergent pencil. There is seemingly a transparent object to the right of Fig. 27: in reality there are two nearly in contact, one immediately behind the other, but not so close but that a focal point may be insinuated between them. They are near the front part of

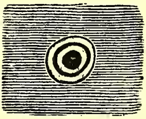

FIG. 26.

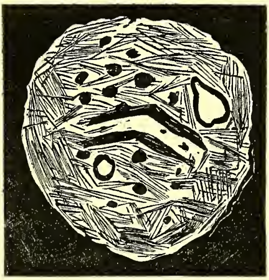

FIG. 27.

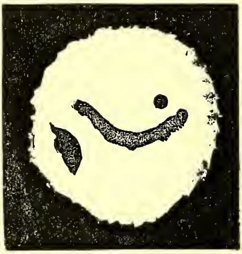

FIG. 28.

the lens. The curvilinear refracting body, whatever it may be, is located behind all the others, and is probably at the posterior surface of the lens. There is no like strongly-refracting curvilinear body in my left eye; but its lens contains six specimens of transparent specks, two of which, considerably apart, and roundish, are lodged at or near the anterior aspect, whilst a group of four pale round ones is found similarly placed with respect to the posterior aspect. It can be said with certainty that the two irregularly-shaped transparent specks in my right eye do not lie in the capsule, or between it and the lens, inasmuch as they have an interval between them. These, at least, are in the lenticular substance, wherever the other transparent bodies may dwell. Oil-drops have been observed with the microscope in the lens; but I should imagine they would not be permanent, as these are. These look like cysts.

29. I have re-examined with scrupulous care the relations of all such most forward lenticular specks, as show themselves near the margin of the pupil, to the iridescent plane, and I cannot find one that is not appreciably behind it. Cramer, Helmholtz, and others, have maintained that, at all events, in adaptation of the eye for near vision, the iris rests in contact with the lens, and helps to compress it for the purpose mentioned. Since I cannot be sure that any one of the specks whose removal from the iris I have tested dwells on the very face of the lens, I am not able to affirm that the iris does never rest upon the capsule. All I can say is, that I am unable to find in this way evidence that it may do so. I can judge of the relations of such objects as have

their places too near the axis of the eye to be nearly approached by the iris even in a dazzling pencil, by moving a focal point, as truly as I can, from contact with the iris perpendicularly to the axis, and observing whether it passes through or in front of the object; or by difference of parallax in two pencils. In such trials I have always believed the iris to be found somewhat in front of the most forward object even. But, owing to the influence of varying ocular refractions that must come into play in such a comparison, I will not put any value upon them. Since the office of aiding in giving additional prominence to the anterior surface of the lens has been assigned to the iris, iridectomy has been much practised, and the observation frequently made, that the accommodating power of the eye has survived the operation; so that the change of focal length can occur, without the iris taking part in it, by means of the ciliary muscle. Hence we are not justified as yet in discarding the old notion of the aqueous humour being divided into an anterior and posterior chamber, though, no doubt, the latter is very shallow.

30. With a fine divergent pencil I see a tuft of bright lines, of a straighter character in the right eye than in the left, and radiating from a point nearer the middle of the pupil,—though generally they are in both eyes in some degree crooked, and only approximately spring from the said middle—whilst finer ones branch from them, and the ends of fainter ones towards the circumference of the pupil peep between them. A few of the largest of these lines plainly carry a dark diffractive fringe on either side. Fig. 29 sketches the style of each tuft; that for my right eye being to the left

hand. If the figure be inverted, each will be an erect image of the *cause* As we carry the focal point towards and into the eye, the lines go on dilating, and thus tending to vanish. Still, after it has been introduced into the lens, the stronger ones are yet discernible, and can be found (11 to 17) to lie behind all the specks dispersed through its substance, by any of several entoptical expedients—by a single or a pair of pencils. By comparing the figures here introduced with Fig. 2, we perceive that the figure now remaining is derived from the stellate structure of the lens, and that it is not too much to say that through these radii the posterior face of the lens itself is discernible, the vertex being shown as their point of origin. If the focus keep on approaching this face, these radii will vanish before it reaches it, and that by a decided interval. These radii or limbs agree in number with those in Fig. 2, or in my left eye just exceed them. Now, with a radiant point at a couple to four inches before the eye, I can count in one organ full twenty-two or more limbs. Whence arise the additional ones now appearing? At such a remoteness of the radiant or of a pair of radiants, the difference in parallax for objects at different lenticular depths is too small for certain observation. By bringing the focus continuously (with two pencils the limbs fade sooner) inwards, I obtain a glimpse of some of the more evanescent lines

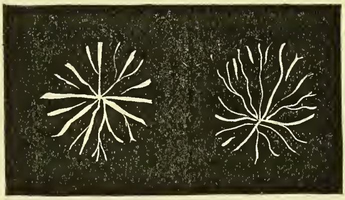

Fig. 29.

—those that have been described as peeping between the others, when it has reached the cornea, or perhaps when it has just entered the aqueous humour; and then, by moving it laterally, I fancy I can detect a parallactic difference between the two knots: indeed, I can just thus discern the anterior face of the lens by its star, and discriminate between its place and that of the other. Let the focus pass slightly deeper, and these limbs entirely disappear, just as the posterior in their turn when it gets near the back of the lens. Upon the whole, I can make no stronger statement than that I can see the latter entoptically, and probably the former.

The reason of my not having hitherto cited the convergent pencil is, because in this instance I hesitate to assert that I can see the objects under investigation with it. In the pair of figures for my right lens, the curvilinear object visible in both pencils runs so accurately along the paths of two strong limbs, that I am unable to distinguish its locality from theirs. If it be they, the homogeneous substance of the lens that produces them must project, ridge-like, beyond the tubular portion of the lens. At any rate, with all the other limbs there is no such decisive coincidence. Notwithstanding, after many trials, I have persuaded myself that I do descry, with the convergent pencil, faint grey radii as representatives of about half-a-dozen other limbs. I may just catch a glimpse of such a shade in my left eye, but never so far as to lead me to fancy as much, had it not been for the encouragement afforded by the other eye. But then the large limbs for this eye are not so well marked as for the other.

In this uncertainty as to the cause of the stellate phenomenon, I observe that in making the eye recede from a lucid point the stouter limbs grow dark at their sides, and put on diffractive fringes just as refracting bodies do. Hence I am led to the conviction that the lamellar portion of the lens does project from its face.

Nevertheless, I cannot rid my mind of the suspicion that some other cause than refraction comes into play, because the visibility of the lucid limbs excels that of the dark ones in so unparalleled a degree. In short, I am driven to the inference that the tubular structure of the lens is not so diaphanous as the homogeneous stellar. When a radiant is near the lens, the rays cut indifferently the two portions, and the limbs are not imaged. But, as the radiant retires, they are enabled to hold their course for a greater distance in the lamellar portion; and, being wasted less than those that pierce the other, they yield bright images. From intervening between the retina and the other star, the hinder one is apt to turn aside some rays that enter the first; and rays that enter the anterior vertex are liable to be confined, by reflection, to the lamellar substance until they emerge at the posterior. Thus the vertex and limbs of the posterior star predominate.

If we reflect the rays of the sun into the eye from the head of a pin, the stellate figure will be seen extending far under the shadow of the iris, seemingly because in this case we see through that muscle.

The image of the predominant vertex usually deviates from the middle of the pupillary. In my case, for my left eye, for a lucid point rather within my reading distance, it *appears* as if lying at about one-third of the ertical axis of the pupil from its *apparent* lower border, and slightly towards the *apparent* left. It has been recorded of many other eyes, that the vertex shows itself towards the bottom of the pupillary image.

31. We have evidence of the universal unsuitableness of the human eye for bringing the rays that hold their course in the homogeneous portion of the lens to a retinal focus, in the fact that the vulgar idea of the form of a star (where it is not confused by embracing phenomena attributable to the eyelashes and fluids on the eyelids) is owing to the structure of the crystalline lens, and that every spark seen rising from the fire wears the features of a star. This remark is independent of the probability that no eye *quite* accurately focalizes again even such rays from a lucid point as are not diverted from their due paths by entoptical objects.

If we look at the points of the teeth of a very fine saw, or a series of white points on black paper (the dotted lines in Figs. 21 and 22 may serve the purpose), thickly arranged in a straight line, held within our least focal distance, the lucid pencil from each of these points will project on the retina not only the bright stellate figure, but images of all entoptical objects, *in all their parts*. The posterior vertex of the lens will be projected on what seems to us the proper images of the points; whilst the resultant series of images of any one object must fall, if not in the same straight line with the vertices, in some other parallel, or very nearly parallel, to it.

Now, if we conceive the number of points to be increased indefinitely until we have the edge of a knife, or a white line on black paper, such edge or line yields, all along it, a divergent pencil in the direction perpendicular to itself. Hence, the posterior vertex will offer us the brightest image of it, whilst other entoptical objects will seem to present others in parallel lines, lighter or darker, according as the elementary image whose multiplication is the cause of it is so.

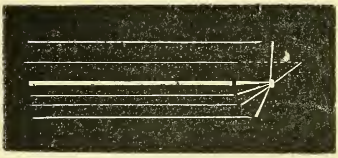

Fig. 30.

In Fig. 30 is drawn, just beyond a straight line, a dot from which issue some of the branches of the star in the pupil. Then, as every branch draws a whitish band along the line occupied by the vertex until it is cut off by the iris, it is clear that the lateral illumination will diminish in stages or breaks made on a level with the terminations of the respective branches; and the more lucid will be the band contributed by any branch of a given size, as this makes a less angle with the line itself. The fine white lines in the Fig. only indicate the breaks of the stages; they do not attempt to show the successive fallings-off of marginal illuminations.

Similarly it can be traced how such portions of the inflective fringes of the iris as are parallel to the line draw fainter images of it about where the marginal illuminations fade from view; just as we have found, in the previous chapter, all bodies upon the eye do whose sides are parallel to elongated sources of light. This observation must hold good even of the fringes of entoptical corpuscles.

Moreover (8), the chromatic dispersion of the eye will be carried along the line so that this will look violet, and the furthest linear tracing red; unless the eye be adjusted for a distance short of that of the line from it, when the order of the prismatic colours will occur contrariwise.

The broader the pupil, the further from the line will these phenomena skirt it.

If we strain the eye with painful stringency towards infinite remoteness, *through* the edge or line gazed at, until a spasm seize its muscles (see Chap. VII.), its pupil will fitfully dilate and contract, and the phenomena in question as suddenly change from a greater to a less span.

It may so happen that the imitation which one entoptical image effects of a line holding any direction, may be effected by some other of a line holding another; and thus certain letters in a page, with an eye out of focal adjustment, may show legible supplementary copies in this way. In any case, the letters will be laterally striped and coloured.

If we regard fine white lines which intersect each other on a black ground, as in several figures of this book, or even concentric circles (see Figs. 25 and 24)—for the imitating lines will not be precisely concentric (9)—the stripes of various shades and hues will be intercurrent, and a gay picture will result. If the eye be strained, as above described, the associated stripes will play among each other, to and fro, in a lively fashion. Inasmuch as it is scarcely practicable to keep the head and eyes strictly at rest with respect to an object viewed, and to retain an unvarying amount of light, and therefore a passive iris, a series of concentric white and black circles, if very fine, will appear to be covered by a tremulous atmosphere. However, it must not be forgotten that we run a risk here of confounding phenomena caused by the eye with those caused by interference of waves of light with one another; for it is well known that colours are thus engendered when radiation takes place from closely-packed symmetrical sources.

Again, to prevent our falling into an opposite mistake, it may not be amiss to recur to Fig. 13. A hair reflecting light into the eye, may be regarded as the edge of the knife spoken of. It must appear striped from ocular causes. The parallel shading in the beams issuing from the flame, had it been all transverse to the rays, might have been considered as indicating this. The striping will be more distinct as the hair makes a nearer approach to parallelism with the length of the flame. An eyelash reflects light into the eye when it lies somewhat without the imaginary lines that join the margin of the flame and pupil; in which case the beam it throws into the eye will exhibit itself detached from the flame, not joined to it, as in Fig. 13. In such case, the striping may be accepted as only ocular; but when the lash encroaches upon the pupil and the beam joins the flame (much less when it stands between the flame and pupil, and two beams project, in consequence, *in one straight line*, one on either side of the flame), inflective images of the flame display themselves. Nevertheless, at the extremities of these beams particularly, simulating ones will be in the series.

32. It may not be out of place to remind some of my readers succinctly of the essential differences in refractive power and focal adjustment met with in the eyes of different individuals. The eye of normal type

is able to accommodate itself for viewing all objects from a distance of about six inches from itself to an infinite distance; that is, to concentrate upon the retina rays from under a certain degree of divergence, to parallel ones. However, some eyes cannot there focalize parallel rays, much less divergent ones, and can see no object distinctly; that is, because such eyes have their principal focus behind the retina. In some, when their utmost adjustment for great distance has been undergone, parallel rays are brought to a focus before they reach the retina, and objects lying further away cannot be defined. Some have a much less range of focal adjusting power than that which characterizes the normal eye. Some have no such power, any more than a glass lens. Some can see clearly at a much less distance than six inches.

33. Dr. Thomas Young, and all subsequent observers, notice a want of symmetry in ocular refractions; so that, for instance, the focal adaptation which would bring those rays from a lucid point, which fall in the vertical plane most accurately to a point, is not the same as that which brings those in the transverse plane most so. He ascribed this to the "obliquity" of the crystalline lens, and mentions that he had been told of persons who held a concave glass obliquely to the eye to remedy the defect. We can observe these effects by marking the shape of a lucid round point as viewed at different distances, when it will continually vary its apparent shape. In the same way, if we view a single straight line at a given distance and turn it round in a plane perpendicular to the optic axis, we shall see it more definitely in some positions than others. The

Astronomer Royal, who is near-sighted, found in his eyes a great difference in the horizontal and vertical refractions, and first used a cylindrical lens to rectify the error. More recently, Donders has called attention to the frequency of such a fault in the eye.

In reference to this subject, I will subjoin, that I once had eyes of the normal type above mentioned, but that for some years past their range of accommodation has been growing very contracted, the left threatening to settle itself to a focal length, for my reading distance, of about nine inches, and the right for rays of from slight divergency to parallelism. With my left, all objects beyond a few yards' distance appear double, the pair of images becoming more widely apart as the objects become more remote. The left-hand image is by far the stronger, and coincides much more nearly with the image rendered by the other eye, although it visibly stands *slightly* to the left of it. To speak more correctly, the pair of images do not precisely appear in the same horizontal plane; but the right, or weaker one, is in a plane a little below the other. If I pass a finger laterally across the eye from either side, the image from that side disappears, and more completely disappears *all at once* if it be passed from the right a little upwards, or from the left a little downwards. It is plain, therefore, that when an object lies beyond the greatest focal length of this eye, any pencil from it is separated into two which intersect in front of the retina. Now, it has been stated (30) that the posterior vertex of the crystalline lens in this eye exhibits itself *actually* rather towards the right margin of the iris; and I am persuaded that the anterior one can be dimly espied to the left of the other. In Fig. 31, there is a

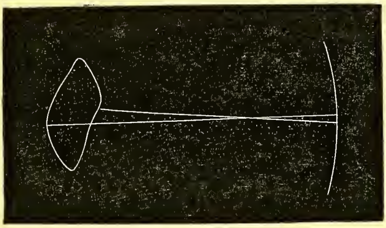

Fig. 31.

section through the two vertices of what I imagine to be the form of the lens; the two straight lines crossing each other in advance of the retina being axes; the one meeting this to the right belonging to the refracting surface at the anterior vertex, the other to that at the posterior. I take it that the lens, in hardening into its present form, has become bent through its whole depth, so as to project to the left, in front, and to the right, behind; the vertices sliding *from* each other to the left and right respectively. This supposition will account for the phenomena of double vision; and proceeds upon like grounds with Young's suggestion of obliquity of the lens to account for, not double vision, but for a want of symmetry in refraction—"astigmatism," as this defect of vision has been lately called.

34. Those who have any peculiarity in the refractive action of their eyes should ascertain its nature, and correct, where necessary, their entoptical observations accordingly. Having hinted at the current deviations from the normal refraction, and instanced, by my own

case, how an individual may analyze such a peculiarity, I must return to general entoptical studies. I need scarcely premise that the limitation of the power of focal adjustment in my eyes may render nugatory with me attempts to detect special manifestations of such adjustment in which others may succeed.

If we introduce a pair of foci to the posterior surface of the crystalline lens, and in equation (b) from 10 in the sense of 12, make $F' G' = \frac{2}{3}$, and $E' F' = \frac{1}{6}$ of the optic axis, we find that an object falling in the pair of convergent pencils at the anterior surface of the lens would have $C' D'$, the separation of its retinal shadows, equal to 5 A B. If we now suppose the retina to retreat from the lens by $\frac{1}{7}$ of the optic axis, or $F' G' = \frac{17}{21}$, $C' D'$ will equal $\frac{123}{21}$ or 6 A B nearly; giving a separation of the two shadows $\frac{1}{5}$th further asunder. We might readily detect such a deviation as the one imagined, did it take place. It is deduced by Dr. Young that the accommodation of the eye from vision for infinite distance to that of nearest distinct vision, through an alteration in the length of the optic axis, would require the axis to be lengthened by one-seventh of itself.* It thus appears that did all this extension occur between the lens and the retina, which the properties of the latter forbid us to accept—for (Chap. VII.) its sentients would be compressed—we could entoptically detect such an alteration. But if the axis lengthen much in its anterior portion, so that objects in or upon the eye move much where we can easily bring the foci into their vicinity, it will be found by substituting the proper numbers in equations (a) or (b), that *very* considerable deviations in the separations of the pair of shadows result. In a word, any change in distance between a tear and the iris, between the latter and a speck in the lens, between any two of these specks themselves, at all approaching one-seventh of the optic axis, could not fail to be observed by the methods adduced. Hence the fact of our not being able to *readily ascertain* (I am not sure that a young person with great scope of accommodation might not detect *some* movement between the tears and iris, or rather between them and corpuscles at or near the anterior face of the lens) that the pair of shadows after the accommodation do vary their apparent distance from each other, in a negative fashion, supports the opinion of Young, Helmholtz, &c., that focal adaptation takes place by a change in the *form* of the lens; as that supposition is the only one which requires a very minute ($\frac{1}{50}$th of an inch in the lens, says Young) alteration in length along the optic axis, without the axis itself being lengthened.

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* Phil. Trans. 1801, p. 53.

35. Young was able to see that when the eye underwent accommodation from for a far to for a near distance, the shadows of straight bodies curved by ocular lateral refraction (9) became decidedly more curved, and that this happened even when the refraction of the cornea was annulled by placing the eye under water; and he argued that there was no way of accounting for this phenomenon but by assuming that the crystalline lens became changed into a lens of less focal length. This is virtually an entoptical observation, and, I should say, by no means easier to make than those just proposed.

If a candle be placed before the eye of another person, it is well known that two erect images of it will appear,—one produced at the cornea, and the other at the anterior face of the crystalline lens, besides an inverted image supplied at the posterior face. It has been pointed out by Helmholtz how we may so observe these images when the eye makes an adjustment, as to see that the lens changes its form principally by acquiring a greater or less curvature at its anterior surface.* It is generally agreed now, that these observations conclusively support the opinion that focal adjustment depends upon modifications of lenticular *form;* though, whether the ciliary muscle be aided by the iris or any other in controlling these results, may still be open to discussion. Thus, those who would search for entoptical manifestation of the manner of focal alteration, should try first whether they can detect that a speck in the front part of the crystalline changes its distance with respect to some corpuscle lodged in a fixed portion of the refracting media.

Sir D. Brewster, in his entoptical paper of 1843, does not find occasion to speak of objects visible in the crystalline lens. In mine of 1845, I show the applicability of the method to the lens, and add, that cataracts are for the most part of so diffused a nature, and the difficulty of instructing patients to examine their eyes in this way so great, that the method proves of little avail for the diagnosis of lenticular disease. "Nevertheless," I conclude, "there are certain species of cataract, true or false, of a more partial character, in which the principle may be used. I hope to make some remarks on our means of diagnosing some of these diseases at a future day." I never fulfilled this hope. It was Listing who (several months later) first published a special study of the corpuscular contents of the lens as seen entoptically. He employed his method of rotating the eye (18) whilst looking through a punctured card. He contributes engravings of the contents of the lens (projected upon the retina), as determined in his manner, from the eyes of twenty-six observers, chiefly men of scientific pursuits, whose names are given as a guarantee of correctness. The observations connected with these engravings, he tells us, have in "many" instances been extended over a year, and in his own to about two years and a half.* From this inquiry, he concludes that in eyes, reputed sound, the lens may display pearl-specks, opaque specks, bright stripes, and dark lines. On glancing over the engravings, it is obvious that I have examples of the first three of these in my right eye (see Fig. 27). Listing places the pearl-specks at the anterior face of the lens, and the dark specks in the lenticular substance, but more towards the same face. If we imagine the clear stripe I have figured (Fig. 27) spread into a couple or three branches at the ends, or that another such stripe cross it at its middle, a good conception may be gained of the stripes in his engravings. He believes them, from the parallaxes reported to him (for he has no example in his own eyes), to be at the anterior face of the lens. My example being at the posterior face, I can attach no weight to the suggestion of one of his friends, that they are indicative of lines of separation of the capsule from the cornea—their surfaces being found in contact in the fœtal state. Until we have such observations confirmed, by practised inquirers, by other entoptical methods, it would be premature to speculate further as to their causes.

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* Encyk. d. Phys. S. 104.

Listing speaks of the remaining phenomena as follows :—"The dark lines, finally, are distinguished from the bright stripes not only by their dark aspect, but also by less breadth, inferior distinctness, and more rectilinear course. They show, for the most part, a radial arrangement, and seem to proceed from the circumference of the pupillary image towards a common centre, which many reach, others not, becoming, as it were, extinct on the way." It is hard to imagine him to have made such minute studies of the lenticular features without becoming aware, if he had not before read, of the lucid star due to its essential structure; but in treating of his subject he does not drop, as far as I can discover, a word alluding to it. These dark lines—only faint marginal indications are discernible in the drawings from his own eyes—take, in all his examples, just the course of the limbs of the lucid star drawn from my right eye. The intervals of the limbs are, of course, by comparison, grey; dark fringes run along the strongest; and in the case of the body I have drawn as taking the linear course of two of the posterior limbs, and of some of the main limbs, there are radial darker limbs bordering it from refraction. If I regard the lucid limbs as exhibiting the normal transparency of the lens, and direct my attention to the interstices, I have before me precisely such another picture of radiating dark lines as those that Listing collects. I not only suspect, but feel assured, that his drawings originated in the manner here suggested. The shadow of an opaque linear body lying in the lens would, by diffraction, display a clear line all along its length, of about the same brightness as the light yielded by the pencil, bisecting the shadow into parallel lines. The shadow of a groove in the lenticular surface, or of a cylindrical body of less refractive power than the substance of the lens, would show, from refraction, an illuminated border in a divergent pencil. No such appearance is noted.

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* "Beitrag zur Physiol. Optik." S. 17.

Listing prognosticates that the disturbing influences of diffraction, and other physical causes, will afford for entoptics a "rich material of future especial investigations," but analyzes none of them himself; and thus his elaborate researches in the entoptical structure of the lens remained defective. The number of drawings he brings together are valuable as evincing how essentially similar are the lenticular contents of healthy eyes: though I think we should be unwise to put too much trust in the accuracy of nice inductions made solely by his entoptical method by unpractised amateur observers, though men of high intelligence. Listing worked under the hope that his labours might throw light on the pathology of cataract. He mentions that one pearl-speck had recently first appeared in one of his eyes: I think it just as likely that he had previously overlooked it. Helmholtz gives an abstract of Listing's contribution as an authoritative entoptical description of the contents of the lens, without improving upon it; and though well acquainted with the lucid star, he reproduces the dark one, without suspecting an error.

According to Helmholtz,* "the manifold images of a point, or of a line, with inexact accommodation, have been made mention of by De la Hire† and Jurin,‡ without their finding the correct explanation. More lately, Th. Young§ described and drew the figures assumed by a lucid point at different distances, and conjectures that the rays might proceed from slight inequalities of the anterior surface of the lens." This statement of Young's views is inaccurate, for he is careful to say that the "rays" must be produced at both surfaces; because, in oblique refraction, two rays may be seen to coalesce. Young made microscopic examinations of the lenses of

* Encyk. d. Phys. S. 146.

† Accidens de la Vue, p. 400.

‡ Smith's Optics, p. 156.

§ Phil. Trans. 1801, p. 143.

different animals, and figures the radiating structure. Helmholtz, it is to be implied, adopts the view that the lucid star is fundamentally owing to refraction.

According to the same authority, several writers had described the phenomena of multiple images (31) the "polyopia monophthalmica of ophthalmic physicians," before their cause was discovered by Gut,* who, according to the encyclopædic reproduction, ascribed them nearly exclusively to the stellate figure. I have somewhat generalized this view.

It would be more correct to view the multiple manifestations as, in certain instances, symptoms of disease than as a disease. I shall have occasion by-and-by to speak of various curious ways in which the sight suffers when the ocular muscles act spasmodically. I have already adverted to the fact that an extension of the manifestations may occur in this way. Here is a wider field for every thoughtful physician to carry on observations in.

Renewed attention has of late years been paid in Germany to variations in focal range of the eye and to astigmatism; but as these subjects are only incidentally touched upon by me, I must pass over their literature. An English account of some of these studies may be met with in a recent work of Mr. Soelberg Wells.

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* Ueber Diplopia monophthalmica. Dissert. Zürich, 1854.

CHAPTER V.

THE STRUCTURE OF THE VITREOUS BODY DETERMINED ENTOPTICALLY.

36. Perhaps it will help my readers to a readier apprehension of the chief points to be kept before the mind in investigating the nature of the vitreous body, if I place before them, as preliminary to entering upon details, something like a definition descriptive of my views of the visible texture floating within it, by which entoptical researches are guided, and the structural inferences to which I have been led after a diligent study of its movements.

From the walls of the cavity behind the crystalline lens, as far as it is lined by hyaloid membrane, there springs into view a lax network of beaded fibre, which is the frame of an invisible membrane that divides the peripheric portion of the vitreous into a certain number of little chambers, separating them from each other, and from a larger middle one.*

These compartments are filled with fluids of graduated density, in such order, that the densest lies next the capsule

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* This membrane being supposed not to line the capsule of the lens.

of the lens, and the rarest next the retina; so that the vitreous body is, in all probability, a compound optical instrument, whose anterior constituents excel the posterior in refractive power.

Before we enter upon the exploration of our visual organs for the verification of this statement, let us consider for a moment what forces are likely to act upon a reticulation thus attached in a cavity filled with fluid, so as to occasion its parts to migrate.

First, it must be remembered that when the globe rotates, the fluids within will relatively rotate. No matter about what axis the rotation ensues, whether about one through the globe's centre by turning in its orbit, or about any other by the movement of the head, or of our whole person, the vitreous fluid will strive to abide absolutely at rest; or, translation of the orbit apart, to rotate within its cavity, through the same angle. But in consequence of the obstructions from the web, if not from some friction between the fluid and the parietes of the cavity, the latter must ultimately concur in the rotation. And as to the objects visible in the fluid, their connexions must exercise control over their movements. Thus we have a modified result, or, upon the whole, the objects in the vitreous will travel in the direction of the rotation, but will start from their places at later respective instants than the beginning of that act; and will then go equally with the rate of rotation. And when the ocular rotation is arrested, they will continue theirs awhile longer, through the *inertia* of the now rotating fluid, until the fluid ceases to move, or until they reach the ends of their tethers; when, after a momentary pause, they tend to regain their original sites as if by retraction, or the web's elasticity. Independently of these connexions, rotation of the fluid in its vessel would cause the objects nearest the wall to journey through the greatest linear spaces, and the others gradually through less, until at the centre of the entire chamber they would remain at rest.

Though the principles here sketched are found on trial to be generally agreeable with the movements of the bodies visible in the vitreous, yet we discover that their operation is disturbed by the influence of a force causing movements solely in the vertical direction *at the instant*, whatever point of the eye's circumference happens to be then uppermost; and which must, therefore, proceed from a difference in specific gravity of some of the contents of the vessel.

If the axis of the eye be horizontal, whether we stand erect or lie on either side, or let the head depend, and we now look to a higher point, the objects in the back part of the vitreous will *actually* (14) rise, as far as their connexions permit, exceeding the angle of rotation far beyond what happens in horizontal rotations, through a considerably greater angle than the axis has turned through; whilst those in the front part of the vitreous will *actually* descend through angles equal to those risen through by the former objects, which are severally at corresponding distances from the wall of the cavity. But if from a horizontal direction of rest we turn the regard to some lower point, both the anterior and posterior objects so accompany the movement as not to rotate at all in the eye. And similar effects respectively take place either in looking from any lower to a higher point, or *vice versâ*, no matter through how great an angle.

Hence the posterior objects are, relatively, so strongly buoyed up, and the anterior ones pulled down by a difference in specific gravity in some of the contents of the entire chamber, as to more than counterbalance the effects of friction in the rotatory act.

Nevertheless, with the optic axis vertical, whether we look upwards or downwards, neither the objects nearest the foramen centrale retinæ, nor those nearest the lens, approach appreciably, or depart from the wall of the vessel respectively nearest them. And it is as much as ever we can detect a very slight vertical movement in objects rather further removed from the wall than either of the examples mentioned. As, therefore, the difference in specific gravity which we have found to exist does not manifest itself decidedly under circumstances when it must have a great tendency to do so, the objects we regard must, immediately or mediately, in some fashion be tied to the parietes of the cavity.

When we wish a deliberate inspection of an intra-vitreous body, we had better look downwards, because this is a direction agreeable to the ocular muscles, and the body will remain steady whilst we survey it.

In setting about the scrutiny in question, the first glance conveys to the mind the impression that the floating bodies we behold are a confused mixture of globules and fragmentary filaments. The most cursory methodical exploration apprises us that all these lie behind the crystalline lens, and by 11 and 12 we resolve that whatever be the breadths of the shadows, under various conditions, all, from front to back of the vitreous, whether filaments or globules, have a general agreement in breadth, so that both in a divergent and convergent pencil increased magnitude in the image shows a less distance from the focal point we employ: though in any given region globules or filaments, side by side, at the same focal or retinal distance may differ *appreciably* in size; and though the most anterior filaments may have a somewhat greater average breadth than the most posterior.

If, to get more accurate information (speaking in terms of an inch), I place a pair of foci $\frac{1}{180}$ apart at the optic centre (15 and 27), the foremost fibre in the vitreous casts in the divergent pencils shadows whose middle lines are *retinally* $\frac{1}{25}$ apart, and which are $\frac{1}{100}$ broad. It is thus $\frac{1}{14}$ from said centre, or $\frac{1}{37}$ from the lens, and has a real diameter $\frac{1}{840}$. The anterior current of fibres seems to extend to fully $\frac{1}{8}$ from the lens, and the breadths of the main ones to be about that of the example chosen, or a little less. With foci $\frac{1}{90}$ apart, one of the most advanced fibres of the posterior current retinally shows shadows $\frac{1}{375}$ apart and $\frac{1}{750}$ broad; another, behind this one, shadows $\frac{1}{1500}$ apart and $\frac{1}{1000}$ broad. These are, therefore, $\frac{1}{8}$ and $\frac{1}{60}$ from the retina, and have real breadths of $\frac{1}{930}$ and $\frac{1}{1060}$. I may see a fibre lying over the *punctum aureum retinæ* within $\frac{1}{60}$ of it, having a parallax little more than the central vessels of the retina, which are, in this region, about $\frac{1}{130}$ from the *sentient surface*, from which we are, in fact, measuring, on movements of a pencil parallel to the retina (17). We must guard ourselves against taking for globules little dark dots or specks, the shadows of retinal capillary vessels, which are brought into view by such a movement, as will be explained in the next chapter.

The image of a globule in a divergent pencil is a brightened circular area surrounded by diffractive fringes; in a convergent one, a darkened circular area, within a fringed brightened areola. The globule, therefore, is transparent, and of greater refractive power than the fluid in which it floats; but it cannot be of much greater, for, were it so, globules residing near the retina would evince shady centres when we receive into the eye rays from a lucid point placed as far, or nearly as far, away from it as its anterior focus (9); for they should then be able to bring the rays that pass through them to a focus nearer to themselves than to the retinal seat of their image, and thus to project them away from the image's middle portion. However, in such a case, we may observe stray globules near the lens with obscure middles. What has been said of the globule may be considered to apply to the filaments.

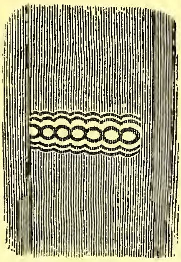

Fig. 32.

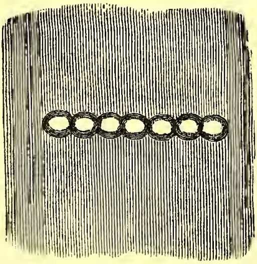

Fig. 33.

The objects near the crystalline lens are easy to see, and therefore could not be attached to its capsule without its being noticed. Whereas, on the contrary, every bead or filament thereabouts sweeps across the pupil, however broad this may be, without any check.

The shading in the figures of this chapter indicates the groundlight of the pencils in which the images appear.

In Figs. 32—4 the string of globules, or portion of filament, is supposed to be perpendicular to the axis of the pencil.

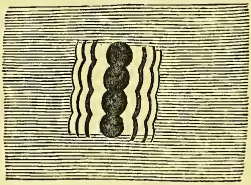

Fig. 34.

In the first of these the string is nearer the radiant point than in the second, whilst the fringes are omitted. The second only shows two external fringes, bright or dark, though in good light it is not difficult to count a half-dozen of either. The third shows the string in a convergent pencil.

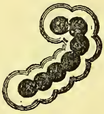

Fig. 35.

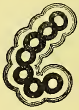

Fig. 36.

Fig. 35.—A portion of a filament in a convergent pencil,
Fig. 36. The same in a divergent pencil; merely to show the inversion in changing the pencil.

If we now single out, with a divergent pencil, one of the smallest images, or a bead nearest the sentient points of the retina, and move the eye about gently, we can note that it accompanies the movement; whilst others nearer it, with broader shadows, pass over it and swim about. If the eye rotate through a very small angle, it does the same, though the others referred to remain at rest, not *yet* having been set in motion. And when the eyeball rotates sufficiently to cause the mass of globules less near the retina to appear to move, they will proceed even after the eye has ceased to move, and will regain their places by apparent retraction; whereas the object we are especially watching moves, if not exactly, *all but exactly*, with the eye, and stops with the eye. If we reflect that the smallest instance of images ever lessening for more posterior objects scarcely expresses the lucid and shady contrasts which reveal it, we can well understand that a like object behind the one that yields such an image would not be discernible at all. So that if all the forthcoming observations shall be found to harmonize with the notion, we may conjecture that a chain of one or more invisible beads is the mode of connexion with the parietal membrane, ending in the "*decumbent nuclei*" that histologists find thereon; especially if there is reason for believing that none of these threads spring from that portion of the membrane that covers the *punctum aureum retinæ.*

If we now turn in succession to objects at different depths in the humour, we observe that their several excursions from positions of rest, consequent upon ocular movement, are in accordance with what we should expect from objects tied together as imagined, under the dynamical influences actually in play. In so far that, though we might never be able to divine how the seemingly solitary globules are retained in their relative places, we might be sure that they are parts of a *system.*

But if we repeat the examinations of these objects in various postures of the head—if we rotate the eye in all the positions it can take, gently, quickly, and strenuously, seizing every advantage for getting as extensive and diversified a sight as possible of the contents of the vitreous,—then we shall readily come to *see* that a host of fibres start from the hyaloid, from place to place, as

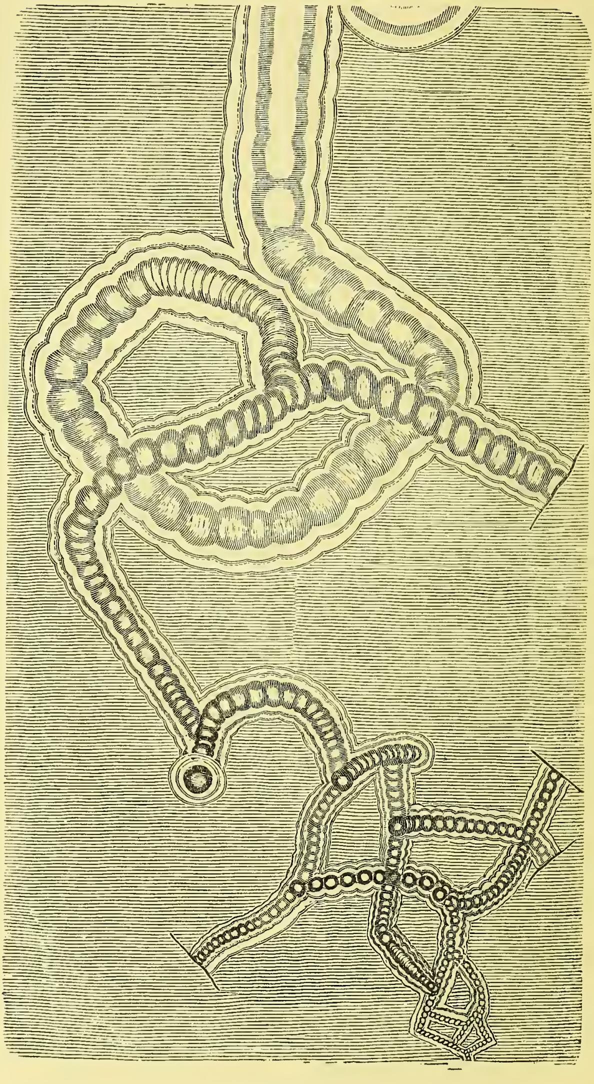

Fig. 37.

far over it as the superimposed retina has a moderate sensibility, and congregate into fibres that stretch out into the fluid. Thus, reversing the description for a given instance, by the gradual tapering of the image through variation in retinal distance, in a divergent pencil, a fibre coming from the depths of the vitreous when the eye is prone, to attach itself above, wears the aspect of a trunk of a tree throwing out branches and twigs, holding by the ultimate subdivisions to the retina, so that in a vehement rotation of the eye the tree seems to fly along space, revolving on its twig-tips (Fig. 37). And, further, it requires but the bestowal of a little pains to make ourselves conversant with the skeleton of a fibrous network stretching all along the walls of the vessel.

Nor can we have omitted to notice that many of the filaments present to us uninterrupted ranks of beads of much length. If closely observant, and our pencils of the best, we perceive that

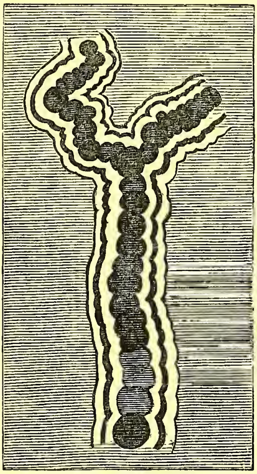

Fig. 38.

A filament inclines generally a little from the vertical direction towards the crystalline lens. Its beads in a convergent pencil have images of less size as they are nearer the lens. The manner in which the fibre bends in various directions may be detected by the outlines of the figure. This figure, like the last, supposes the thread only to deviate from one plane within certain limits, that it may not be drawn broken into pieces.

every filament in a plane parallel to the back of the eye, or crossing the axis of either kind of pencil at right angles to it—that is, *at least approximately intersecting the rays of the pencil in this style*,—is resolved into a thread of beads. If the filament bends in such a plane, the consequent crowding together of the beads on the concave side is manifest.

Now, if a filament at any part quits such a plane, the images of two or more portions of it, which may have afforded each other inflected and refracted rays, must be projected upon the same retinal spot; and considering that the filaments may cut the vertical transverse plane at every angle, that they may have every degree of tortuosity, are exceedingly plentiful, and the beads innumerable, the interference of their projections with one another must be of inconceivable frequency, and the resulting phenomena in all possible ways diversified. In such a case, it may be observed, it is neither the object which first intercepts a pencil of rays, nor that which last falls in their path, which is revealed by preference: as a rule, it is that whose image has the most forcible contrasts in bright and dark parts; in a divergent pencil, more commonly, though not necessarily, the hindmost object. Ordinarily, neither image extinguishes the other, and even all the bright and dark parts of several such images may be distinguished at a retinal spot. Yet events of another character may accrue: a couple of images may own a common centre, and coincide in their concentric fringes, generating an image of intensified contrasts. This effect is often produced if a filament bends sharply forwards. Again, the reverse of this happens by several images of beads dropping upon one another in such a fashion as to slur all the contrasts together, to their entire obliteration. Thus we have a continuous perfectly-beaded thread severed into pieces, severally comprising either many beads, or but a few, or even a single bead. By causing a fibre to twist in the eye, or by bringing the images of anterior beads of a fibre inclining forwards from the retina, over those of posterior ones, by aid of their different parallaxes when we move the focus of our exploring pencil from side to side, up and down, and as occasion requires, we may produce at pleasure phenomena of all the sorts that are here described. What has been said is equally true of the anterior fibre in a convergent pencil; for if it be bent to and fro in the stated plane, it yields a broken rank of sundered black patches produced by one or

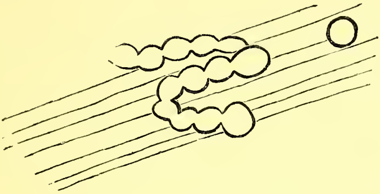

Fig. 39.

In Fig. 39, the plane of the paper is such that the axes of all the beads in the fragment of thread lie in it. The straight lines show the directions of the rays of a divergent pencil passing from left to right, towards which on either side the thread bends abruptly from a larger bead, so that to reach this they must pass along either series without suffering more refraction than they would at the surface of a single one, and if just touching the series are intercepted by this one. The consequence is, that the bead behind which the circle is drawn, is the only one that appears. By difference in parallax, the connected loop of filament may be made to come forth. This illustration of one of many modes in which this result may happen must suffice.

more beads, the beads in the intervals being then invisible.

Keeping, then, this hint in mind, and perseveringly disentangling the fibres, we may soon perceive that they are all mere strings of beads, which coalesce by contracted surfaces. Here and there we may note some stouter than the rest, with perhaps their beads more broadly united, constituting, as it were, a stronger framework ramifying through the general web. We may also discern a portion of fibre much finer than the average.

But it may be better to speak directly of what I find in my own eyes. I have, then, quite familiarized myself with the webs—having a systemic but no further similarity to each other in my two eyes. I can at once locate in the tissue any thread that comes into view, and any globule that tumbles upon the sight I can restore to its place among the meshes of the web with facility. Again and again I have succeeded in stretching a host of seemingly disseminated beads into a tuft of neat fibres. And a number of them scattered separately among the meshes I have been able to distinctly assign to one or more crumpled fibres twined in among the rest. And if I have occasionally been unable to get a continuous inspection of certain fibres confined by others, I have dotted out their course satisfactorily by the line which the projected beads indicate. Whenever I have been able to cast a swarm of plain circular images tolerably free from coincident projections, I have not failed to discover that they are constituents of fibres. In all the examples of the anterior portion of the vitreous that fall within the reach of our convergent pencil, it is quite obvious that there is not a stray bead, and that all the fibres are series of beads. There is an instance in which I have been a little puzzled to resolve fibres into beads: it is that of two parallel vertical nearly contiguous ones in my right eye, lying somewhat away from but opposite to the optic nerve. When brought into view by turning the head to the left, parallel lines, as if the image of a cylindrical refracting body, just as is shown at the upper end of Fig. 37, appear. By a strong rotation of the eye, however, both fibres exhibit themselves, twisting gently round each other like the threads of a rope which is broken up into equal fragments by the vanishing of all coils having a certain direction. The beads then reveal themselves. They can also be discerned, without this device, by a lucky placing of the source of a divergent pencil. Besides, these threads are only two among a number which form a sheet of network thereabouts, which lies in the path of the incident rays of light and disperses them.

Nevertheless, in the immense multitude of beads, I do fall in with some so involved among fibres, or so widely away from the axis of vision, as scarcely to afford an opportunity for the establishment of their being items in a series; and a small group of beads, the nearest to the most sensible portion of the retina, where no contiguous ones are apparent, but which may be presumed to be merely displaying unusually strong images in a position where ordinary ones are not discernible; and these are plainly held in their relative places in the fluid by some means or other. So that, from all these observations, I feel all but absolutely certain that every bead forms a link in a fibre, and certain that there are no *loose* beads in the vitreous.

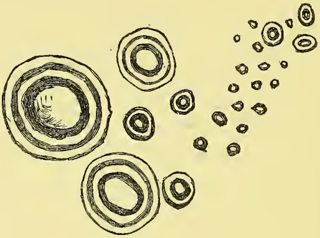

Fig. 40.

A group of least images from my left eye, scarcely fringed, with a few stronger ones among them that I cannot bring completely into threads. A few large free *images* are superadded.

The network, I see, is not a mere medley of fibres in a space of three dimensions. Arising thickly, but not indifferently, from over the surface of the hyaloid, they unite in detached groups, and the junction of these groups in the body of the fluid is not effected by fibres running in indiscriminate directions, but by fibres interlacing and anastomosing in such fashion as to form trellised *sheets* of tissue, some of the sheets being so replete with threads as to be almost a cloth of them, whilst others show them with considerable intervals.

Insomuch that these sheets, or fibrous lamellæ, are arranged like rudely-latticed dissepiments, traversing in a more or less continuous expansion the vitreous, with more freedom of movement as they reach further from its wall, along which they chiefly prevail, only extending into the interior obliquely; this account of the appearance of the vitreous body when prepared in chromic acid, involves a fair notion of what I am

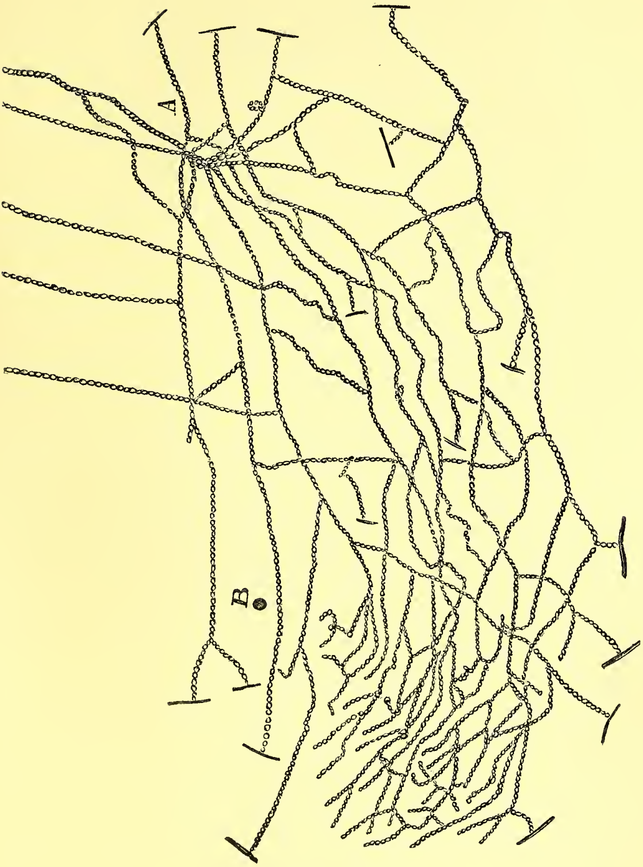

FIG. 41.

A portion of web from my right eye oscillating at about $\frac{1}{10}$ of an inch from the retina, stretching from in front of the foramen centrale retinæ B towards the nose. It is drawn inverted. All the fibres lie in one sheet, except where little cross lines indicate some that turn off into others. It is not an entoptical appearance, but, as inferred, the web itself magnified about 16 times, and should, to be complete, be supplied with numerous smaller fibres.

striving to convey. "A few concentric lamellæ externally, to which succeed very irregular radiating septa, and lastly, an irregular central cavity." Only the word concentric must merely import that from the extension of the lamellæ near the wall, much of it takes a direction nearly parallel to it; the fibres run as if in the septa of a number of cells, whose mean shape is expanded parallel to the parietes of the vessel, and compressed in a direction perpendicular to that, just as the elastic fibre of histologists is known to do in serous membranes, or homogeneous connective tissue, of which sort of fibre they would seem to be. These reticulated septa are woven, as it were, from the hyaloid, but span the orifice of the pupil without springing from the capsule of the crystalline. Nevertheless, no membrane is visible in the meshes; nor could any homogeneous material of this sort be seen, if existing. There is a deceptive appearance of membrane when a bright pencil of light is carried parallel to a sheet; for the images of the fibres, armed with broad series of fringes, which occupy the meshes, move as one plane.

Such seming, then, to be all the results obtainable by detailed inspection of the web, let us bring forward the observations on difference of specific gravity which were left imperfectly interpreted, and try whether the unknown in the two cases may be arrived at by considering them together.

We shall hardly be inclined to conjecture that a fibre that looks alike in all regions should be lighter than the vitreous fluid posteriorly, and heavier anteriorly, even though, according to our actual measurements, it be somewhat stouter in front, or that it, together with the membrane in which it runs, is so. If thus, and the fluid freely communicates with itself throughout the vessel, when we look downwards the fibres in the vicinity of the lens would fall down upon it, and those near the retinal centre mount up against it.

Not only, however, do they not do so, but these fibres suffer hinderment whenever they would move parallel to the optic axis. But what is a point of great moment to observe, is that this hinderment, after all, is not absolute. To take the easiest instance for detecting this fact: in looking from the horizontal direction to the prone, the posterior fibres swinging parallel to the retina drop downwards, visibly growing larger, and displaying an additional parallax, as they rotate about their apparent tips. Hence they have positively sunk as if heavier than the fluid, whilst their rotation round their tips shows that there is no membranous texture intervening to prevent buoyant bodies from rising to the surface. Evidence might be found, too, from nicely studying the slight movements parallel to the axis that really do occur in both anterior and posterior fibres when we turn the eye to the zenith or nadir, incompatible with the notion that the movements of the threads are due to a difference in specific gravity between them and the fluid. Even the lateral movements, say, of the posterior fibres, as regards the rate at which they move under the action of the force of gravity, as they are situated at different distances from the retina, could be shown to be inexplicable by the notion in question.

But since the parts of the network do not uniformly move in the fluid as if they were of greater, or of less, or of the same specific gravity as it, and are notwithstanding subject to relative displacement under the action of gravitation, there is no other conceivable alternative than that the vitreous fluid is contained in shut membranous bags, and that the force shows more energy in the anterior than posterior ones, causing the whole to move together, because the fluid is not free to circulate.

Were it likely to be imagined that the fibrous network we have been tracing runs elsewhere than in the membranes whose existence we have arrived at by clear induction, I dare say that it might be demonstrated entoptically that it could not do otherwise; and if it could, the need of the hypothesis beneath would not be annulled.

Were it likely to be imagined that in the case of membrane whose elastic fibres seem of equal distribution behind and before, the texture of the bags themselves is heavier in one part than another, or preponderates in front by a difference in quantity, carrying the fluid contained in the bags with it, one might not despair of showing, from the character of its parietal attachments and movements, that the supposition is untenable. Looking upon these contingencies, like the one just disposed of, as not meriting discussion, I adopt the only other hypothesis, which is—

That the fluid in the anterior part of the vitreous is of greater specific gravity than that in the posterior,—
and all difficulties in explaining the entoptical facts derived from the vitreous quickly melt away.

Fig. 42 shows a vertical section along the optic axis of the membranes of the vitreous, in accordance with the scheme inferred, the axis being horizontal. The foremost membrane with the lenticular capsule encloses fluid of the heaviest sort, which therefore depends in a lobe below the level of the lens. The second membrane embraces the first, and with its aid holds a second bag-full of fluid, which being dense, hangs down from the first. The fluid between the large central bag and the last striving also downwards, has forced the central one to rotate, so as to cause all the membranes that attach it to the walls of the vessel to lean towards it, below to the right, above to the left. Behind the central one are bags of lightest fluid, and these necessarily, as far as the length of membranes permit, swim to the stop, as is expressed by the sharp curves that bend in a similar style, one beyond the other at the upper part of the three last membranes. It will be observed that all the membranes attached to the vessel are drawn stretched, as if the whole body of vitreous fluid had rotated in a direction from the lens to the bottom of the eye, and so round. Any number of cross connections, and variously inclined to them, may be superadded to these membranes without injury to the scheme, provided that they all be stretched in conformity with it. A few more connecting membranes, as I deem ought to be the case, would have been drawn behind and before, did I not fear

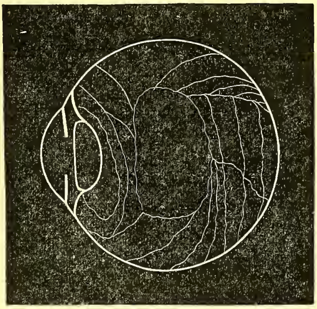

Fig. 42.

embarrassing the apprehension of the reader with too intricate a figure. Besides, I infer that in the recesses behind the lens and along the walls, out of the way of inspection, several membranes exist approximately parallel to the wall, just as before or behind, and that, with allowance for variation in conditions, they have movements like the others. The conception of a series of diminishing membranes of similar form with the vessel, one within the other, and fastened by radiating membranes to it, if fluid of the proper densities be assigned to the loculi of the different regions, would satisfy all the requirements I aim at.

Now let us suppose the head turned upside-down until the optic axis is again horizontal. It is obvious that the relative weights of the bags of fluid remaining as before, the whole body of vitreous fluid will rotate *with respect to the vessel* until the membranes that spring from the walls are inclined to them in a like fashion in the opposite direction. The middle bag will have turned, as it has free liberty to do, through a very large angle, the front membranes will have been warped over to the other side of the lens, and the hind ones will have transferred their overlapping curves or flexures to the other side of the optic axis. If the membrane can do this, its parts can rest in any intermediate position; and what has been done in the vertical can be equally done in any other plane in which the optic axis lies. In a word, all the excursions of the fibres which have been detailed are in exact accordance with the conception—the confined ones for those near the retina, the greater ones for those further from it, until at the most anterior of these they sweep, as they may plainly do by the figure, through a linear space of the third of an inch. Then, again, the fact of anterior ones flitting across the pupillary aperture is accounted for; also the certain, though very slight, amount of freedom enjoyed by the earlier and later fibres in the direction of the optic axis, and the twirls of some fibres when the eye is forcibly rolled in its socket, as the membrane is not so tightly braced but that portions of it may be much twisted by eddies impressed upon the fluid.

We have merely insisted that the densest fluid resides in front; but were we to assume, further, that the vitreous is an aggregate of bags which are filled with fluids of graduated density, the specifically heavier, in any two examples, always lying nearer the lens, the visible movements could be no other than those we witness.

If the internal rotation be produced solely by a heavy loading of the bags adjacent to the lens, the rest of the fluid being of uniform density, the tackle, if I may so speak, must be adjusted with singular nicety, to compel all the fluid of the vitreous under the action of this weight to move in a rotatory manner, and not to crop up sometimes in a direction opposite to such a current at the posterior portion of the central bag. Again, if the remainder of the fluid be of uniform density, there seems to be no end gained by so nicely subdividing it. Indeed, why, under a condition of such uniformity, enclosed by slack tissues, should the posterior fluid *always* tend to mount to the top, when from its specific gravity it might rest anywhere? It is hard to conceive any reason for such constant deportment.

Thus, without suffering myself to be carried away by too much confidence, I find my mind disposed towards the view of a gradation of density.

37. We will now see how far the foregoing notion of the vitreous textures is borne out by the researches of anatomists. According to Todd and Bowman's Physiological Anatomy*—"The *vitreous body*, lying in the concavity of the retina, and filling all but about the anterior fifth of the globe, has, when entire, the consistence of soft jelly. It consists of an exceedingly fine and close, but perfectly transparent web of fibrous tissue, the meshes of which are exceedingly small, and contain an aqueous fluid. If the tissue be cut into, the water will slowly drain off, showing the continuity of the cells with one another; and the manner in which they are constructed by interlacing fibres may be very plainly seen with a high power near the ciliary processes, in the vicinity of which these fibres are particularly strong. The whole vitreous body is bounded by or contained in an envelope of extremely thin homogeneous membrane, having corpuscles or cell-nuclei on its inner surface, where the fibrous tissue is attached."

It does not follow that the cells communicate because the water slowly drains away when the tissue is cut into; for in such case the delicate membrane has to bear the weight of the fluid above it, which *in situ* was sustained by counter pressure of the rest of the fluid. Besides, it cannot be intended to be conveyed that the fluid will all drain away in this way, *leaving the membranes behind;* for if this be so, the obstacles to discovering the structure of the vitreous could never have proved so great, that even now the foregoing description is far from receiving the general assent of workers with the microscope.

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* Vol. ii., p. 31; 1856.

The next page appends, after describing the capsule of the crystalline lens,—"To the whole posterior surface of this capsule, and to a very narrow circumferential portion of its anterior surface, the fibrous structure of the vitreous body is firmly attached, the hyaloid membrane itself not passing behind the lens." I am bold to affirm that there must be a mistake here, and that the fibrous structure is not so attached at the back of the lens. If seen thereabouts under the microscope, it was not connected with the capsule. In an entoptical description of this fibrous structure of the same year, preceding this publication, I particularly insisted upon this obvious fact.

Kölliker's Manual of Human Histology,* after quoting with some approbation from Bowman's Lectures, that "in the eye of the adult, in chromic acid preparations, a few concentric *lamellæ* are found externally, to which succeed very irregular radiating *septa*, and, lastly, an irregular central cavity," goes on to protest "that these *lamellæ* formed by chromic acid also cannot be demonstrated as true membranes, and that in the fresh vitreous no trace of them is perceptible." Then, again, after acknowledging with some reserve that a fibrous structure may be met with in fœtal eyes, he declares,—"Of membranes such as Hannover" (who had found results roughly resembling Bowman's) "describes, I have never seen any certain indication with the microscope; and yet such membranes, did they exist, would incontestably be as easily recognized, where they are folded, as the excessively delicate hyaloid membrane itself. In the vitreous body of the adult, of the previous conditions there was usually nothing left but the homogeneous *matrix*, the cells having disappeared; I noticed the latter, however, in many instances, though rare and indistinct, particularly in those parts of the organ bordering upon the *lens* and the hyaloid membrane in general." The fibres in the vitreous may become broken or folded, so as to show under the microscope only single beads, or cells, or nuclei; so that were it a question of deciding whether there are free nuclei in it or its membranes, the same liability to error exists in microscopical as in entoptical explorations. Moreover, since the membranes of the vitreous are capable of an internal displacement, no value can be placed upon the shape assigned to the central bag, or the directions of the dissepiments proceeding from it, as determined by the microscope.

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* Sydenham Society, pp. 387, 388 (1844).

Upon the whole, I think it will be agreed that in a subject in which such excellent microscopic observers are not in accord on account of the difficulty in seeing the objects to be investigated, their labours give, after all, a general countenance to the present entoptical induction.

38. It will be asked, how are fluids of different densities to be kept asunder by their membranes? To this it may be replied, that the vitreous fluid may be regarded as one of those colloid solutions, which, Graham has shown, are slow to permeate membranes. It is not improbable that a dense secretion may be

poured out from the ciliary processes, from which the thinner portions may filter into the other bags, and be removed by absorption at the periphery of the humour. If there be saline (Berzelius found chloride of sodium and extractive) ingredients present, they may readily thus pass onwards. That fluids of different densities may be kept apart in the adjacent bags, is scarcely more recondite than that the aqueous and vitreous humours should not intermix and equalize their densities through the ciliary folds.

It cannot be objected that the fact of one portion of the vitreous fluid being heavier than another cannot be demonstrated on the dead eye; no cautious, if any, investigations into the matter having hitherto been made. For such a purpose fresh human eyes should be used, and the apparatus for testing specific gravities delicate. I conceive that it might be feasible to introduce through the ocular tissues into the anterior part of the humour a chip of some white substance of less specific gravity than it, and watch through an ophthalmoscope whether in rotating the eye it might not, through getting entangled in a septum, move contrary to what a lighter body should do; or a slightly heavier body into the posterior part, and watch in the rotation through the pared-away tissues whether it might not rise in the eye, instead of sink. Or, perhaps, a few drops of the anterior fluid might be withdrawn by means of the syringe for subcutaneous injection, and its place supplied by another, as melted fat, which hardening in becoming cold, might form a small white mass visible through the ophthalmoscope of less specific gravity than the fluid. It would be better for the eye to remain in the head for such an experiment: a portion of the orbit as well as some thickness of the tissues might be removed from behind, if we wish to watch the movements contemplated from that direction. I find it difficult to obtain fresh human eyes, and have had no leisure to institute careful observations upon the eyes of other animals.

Though it does not follow that unlike fluids have greater refractive power as they are of greater density, yet, in like ones, the chances are that the denser fluid will refract more strongly than the rarer. I have only met with one attempt* to compare the refractive indices of different portions of the vitreous body. The author tells us that "his principal aim, in the present instance, was to submit to experiment the opinion put forth by M. Vallée, relative to the existence, in the vitreous body, of a series of layers whose indices of refraction varied progressively from before backwards." He employed the fresh eyes of ruminants, and "detached" the portions that he proposed to examine; a plan likely to lead to error, as the more highly refracting fibres might be thus tested rather than the fluid. The first and last bags should be tapped, and the fluid drawn. He thinks his observations confirm Vallée's theory, but in a degree far inferior to its requirements. These results, which are at variance with what my conclusions would lead me to expect, remain unsubstantiated by other observers. In any case, they were not obtained from the human eye.

39. In an article in the North British Review,

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* Sur les Indices de Réfraction du Corps Vitré : Note de M. Pappenheim (Extrait). Comptes Rendus, xxv. 901. (1847.)

which I shall soon have occasion to quote, Brewster tells us that Vallée is the only writer who ever conceived that the vitreous body is a compound lens.* But he objects, in conclusion, that "if the fluid is in closed cells, it is impossible that laminæ of equal density could exist in each cell concentric with the crystalline. But, independent of this difficulty, the fibres and muscæ floating within the cells would necessarily bring the fluid in each of them to the same homogeneous condition." It is from these very fibres that I derive my proof of a peculiar constitution of the vitreous. The idea of the nature of the cell in this objection is very far removed from that which I entertain. Vallée's notion was founded mainly upon the theoretical grounds that achromatism could only be effected in the eye by a series of layers of diminishing densities extending from the lens to the retina—being thus led to a general conclusion the reverse of mine as to the direction in which the density is augmented. It does at first strike the mind as an absurd proposition to represent a fluid which is subject to be disturbed by the movements of the body as a compound lens. And, indeed, when we consider the contortions that the fluid in the middle of the vitreous must undergo in the rotations of the eye, unless it be tightly restrained, which we can actually see that it is not, we must be at a loss to understand how the middle layers concentric with the crystalline could preserve anything like their form in different positions of the optic axis. No optical theory has had anything to do with the production of the scheme of the vitreous I advocate: I only ask, after it has been arrived at, whether it suggests any optical purpose. First of all, I think it will be conceded that this cellular arrangement does not become greatly deformed whether the eye looks upwards, downwards, or on the level. I do not pretend to have determined that the section of the middle bag in the figure exactly corresponds in size or shape with the original; but it is palpable that with a proper distribution and lengths of radiating connexions with the vessel, the shape of such a central bag may be maintained with tolerable accuracy in spite of the movements of the eye. Then, again, whether the dependent lobe of the anterior bag be thrown to the opposite side of the lens or be spread all round its margin when the eye is prone, this layer, if the quantity of fluid in it be not too much, may still have a convex surface towards the retina. When the eye is turned upwards, the weight of this layer will give it a convex surface, as it will stretch the bags to pull at the attachments of its membraneous septum round the lens. Without going through the possible deviations in the forms of the different fluid lenses that make up the vitreous, or grappling with the question, whether there may be, in the modifications which gravity may impress upon the parts of this system of lenses, a compensation such that the final refractions of the rays that traverse the vitreous may remain much the same through all these modifications, it may be remarked that the vitreous body may fulfil its functions as well as the crystalline lens does its, and still be open to be charged with imperfections. But if the vitreous be a combination of lenses, of what advantage is this to the sight? Layers concentric with the crystalline, of diminishing densities, may be regarded as merely continuing its principles of construction beyond its own boundary; but inasmuch as layers spanning its surface must be traversed indifferently by all the rays of light that enter the pupil, they cannot aid the nucleus of the lens (7) immediately by their graduated densities in correcting spherical aberration, whatever they may do by the form of their surfaces. However, it is palpable that the provision must influence the focal length of the organ, and its manner of focalizing pencils of light. By fitting together in a row convex and concave lenses which differ in dispersive powers, the compound instrument may be achromatic; but this is consequently not of very short focal length, like the eye. The fact of a large central bag existing in the vitreous, is remarkable enough to deserve more consideration as to its optical effects than it can receive here. Supposing it to have an anterior surface convex towards the vitreous, even though it refract more weakly than the preceding bags, it may lessen chromatic dispersion; and though its radiating attachments to the vessel may tend to retain for it a convex surface towards the retina behind, yet I am not sure that the effort of the posterior bags to rise by their buoyancy may not cause this surface to bulge in the opposite direction. I have figured the section such as it appears to me on observation. I judge by the directions the fibres hold, and their movements; but to decide this with certainty, if it could be done entoptically, would require very numerous nice measurements. With these few comments I must quit this part of my subject, merely venturing to add that I feel assured that it would repay the trouble of any one skilled in investigating the properties of compound lenses to calculate the effects of lenses strung together as imagined here. It may be worth while, too, to investigate the forms that a chain of such fluid bags must assume when filling such a vessel; and, of course, to try to ascertain the actual indices of refraction of the fluids. The ciliary muscle tends to pull forwards "the more prominent parts of the ciliary processes which approach the lens." It must thus alter the form of the densest layer of the vitreous, and must have some, though it may be unimportant, effect upon the optical properties of the eye.

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* Troisième Mémoire sur la Théorie de l'Œil. Par M. Vallée. (Extrait par l'auteur.) xiv. 481. (1842.)

40. The character of the grey images of fibres of the deeper bags of the vitreous seen in the naked eye in the diffused light of day has, I believe, been invariably slurred over by entoptical writers, as ordinary or else diffractive shadows attributable to the proximity of the body to the retina. Yet, if attention be paid to the subject, it will be clear that the phenomenon has a peculiar origin. In Fig. 43, let the centres of the pupil and of the bead of a fibre lie in the plane of the paper. From either edge of the pupil draw two lines, *pa*, *pb*, touching opposite sides of the bead, and ending at the retina; so that the bead has four tangents. Now, in the diffused light of day, the pupil, the window of the deeper chamber, is an illuminating surface throwing rays from every point on every point of the retina. Again, rays issuing from *p*, *p*, in order to pass through the refracting bead must intersect

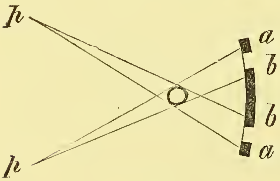

FIG. 43.

each other earlier than the tangential lines *pb*, *pb*, and impinge upon the retina at points further asunder than the length *b b*, that is, if they continue their course as straight lines; and, therefore, as they are made to intersect earlier than they would otherwise by the refraction of the bead, they will be still more decidedly further asunder on reaching the retina than *b* is from *b*. To this we may add, that what is true for rays issuing from the points *p*, *p*, is equally so, in principle, for those issuing from any pair of intermediate points equidistant from them: these, though perhaps not tending to converge so soon as the lines *p b*, *p b*, nevertheless have their convergency hastened, and are made to deviate more or less widely from the imaginary point of bisection of the line *b b*. The effect of all this is, that (something like what happens when we use a pencil of light converging to a single point) the majority of the rays from the pupil are warped away from the middle of the image of the bead to its circumference, and we have a shadow-like central area, whose diameter we have indicated in the figure by the stout line extending slightly beyond the points *b*, *b*, within a bright ring—or say clear ring, for it is but little illuminated beyond the average field of view. The last fact is to be accounted for thus:—Had (to use astronomical language) the bead cast a real shadow, or umbra, *b b* would have been its diameter; and outside of this there would have been a partial shadow, or penumbra, extending as far as *a*, *a*. Furthermore, it must be remembered that the rays that fall upon the bead from any pupillary point near the tangential line from that point, do not penetrate it, but, hitting it at a greater inclination than the critical angle of refraction, are reflected away from it. Hence we see that the clear ring, occupying the region of the penumbra, fails to be remarkable for amount of illumination.

The penumbra spreads outwards beyond the limits attained by the rays refracted by the bead, and encircles the clear ring as a shadow-like one. This is indicated in the figure by the short, thick lines at *a*, *a*, whilst the space left between this and the longer thick line corresponds to the clear ring. I repeat, that these grey phenomena are not caused by the blocking of rays from their course by opaque or partially opaque bodies.

There is (see Fig. 44) an imperfect simulation of diffractive phenomena in the concentric circles, though in diffused light such phenomena are rarely sufficiently intensified in special parts of an image to become apparent. In scattered examples, the two kinds may

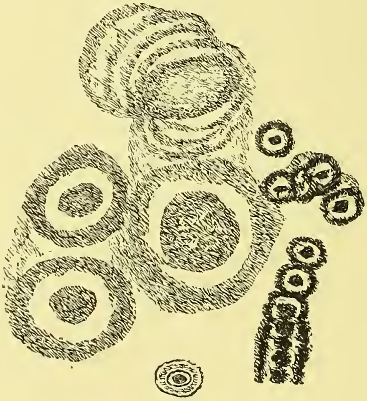

Fig. 44.

show themselves in one image, an instance of this being sketched at the bottom of the figure, in which may be marked the central dark area and the dark ring of the penumbra, with a diffractive ring within and others without it. Some stray images have minute *white* centres, and, in a hazy type, a great many diffractive rings; owing, doubtless, to the interference of rays passing near the tangential lines from the margin of the pupil to the opposite sides of the bead.

Fig. 44 copies from the open naked eye in daylight the images of portions of fibre at different removals from the retina; some being parallel to the pupillary and retinal planes, some inclined to them in one plane, and some coiled in space of three dimensions; portions being unrendered to view wherever twists override each other in a direction perpendicular to the planes. As the images widen and fall upon parts of the retina receiving more of other light, so their grey parts become less marked, until for objects near the crystalline lens there are no images visible.

It is not for a physiological purpose that I am at so much pains to dissect the nature of these images; it is for a medical. In retaining the term *muscæ volitantes* in the vocabulary of symptoms, it is of great moment that we should at once be able to discriminate between pathological and physiological ones. In times past, the images just discussed, an accident of the essential structure of all human eyes, have oftener been called by that name, than images of morbid products in the eye, or morbid impressions upon some portion of the nervous system. Such a knot as that at A (Fig. 41) may project a considerable grey image upon the retina. In the middle and upper part of Fig. 44, I have actually drawn after it. To any observant person, a large portion of the posterior fibre is visible, though mostly only discernible with dim or pale features. Its manifestation is independent of the focal length of the eye; though persons with defective focalizing power are more apt to discover their presence, because they are often anxiously inquisitive about the phenomena of their sight. Intelligent children can be made to see them without difficulty; though such careless natures are not likely to fasten their attention, of their own accord, upon these flitting spectres. For the contrary reason, persons who depend upon good eyesight for a livelihood or pastime, or who are of a melancholic turn, are very apt to brood over them. It has been laid down as an easy way of distinguishing between such muscæ and blind retinal spots, that the latter remain fixed when we keep the eyes directed to a given point. But, in reality, if the eyes be brought to bear, as is commonly done, on the top of some high object, that the suspected image may be viewed against the sky, they have an almost irresistible tendency to drop, and thus to cause the blind spot to drop also; and it is only in a patient of some understanding and thoughtfulness that this test can suffice. Besides, some of the profoundest fibres have images that do not move much along the retina. The blood-vessels in the retina are visible by their shadows, which are only manifest either when the heart pulsates, or on quick rotation of the eye, and therefore cannot be spoken of as fixed muscæ. There are muscæ complained of by patients suffering from diseases in which the blood is of poisonous qualities, or the nervous system exhausted, as in delirium tremens and fevers, which are merely (like dreams) the results of efforts by a suffering brain to realise impressions made upon it. To any one versed in entoptical phenomena, and the symptoms of such constitutional diseases, no difficulty can occur, except perhaps in some very rare cases, in making a correct diagnosis; though to accomplish this end by a few summary rules, I regard as hopeless. Moreover, the introduction of the ophthalmoscope, a few years since, for nosological investigations, has relieved the medical man of some of the most formidable of his difficulties in the diagnosis of diseases of the eye. If an object can thus be seen floating in the vitreous of a patient's eye, we may be sure that it is not merely physiological. Moreover, its size must be such that there will be but little risk but that a patient of good common sense, under proper guidance, may follow the motions of such a body entoptically without confounding it with the fibrous network of the vitreous.

41. Under the head of "Ophthalmoscopic Muscæ Volitantes in a very Myopic Eye" (Medical Times and Gazette, 1861, p. 465), I have published a case in which I determined, by both modes of examination, that some morbid flakes visible in the patient's vitreous moved just as the fibres in the anterior part of the vitreous, whilst the fibres both in the anterior and posterior portions moved as in a normal eye; from which the conclusion may be drawn that the septa of the vitreous had not been destroyed, and that the flakes may be attached to or may lie in the anterior membraneous septa. I gave the muscæ this name to distinguish them from

merely entoptical ones which are normal to the eye. They might be termed *ectoptical.*

42. In the Ophthalmic Hospital Reports, 1859, p. 280, is a paper, by Mr. Dixon, entitled "Extraction of a Foreign Body from the Vitreous Chamber." In this case, a chip from a chisel flew through the lid and sclerotic at nearly on a level with the upper border of the cornea, and about a line from its inner edge into the vitreous. After the wound was healed, on examination by means of external illumination by a lens in daylight, or an ophthalmoscope, it is recorded that "at a sudden turn of the globe, there started from behind the inner portion of the iris an oblong, black body, which was instantly recognized as a chip of metal. It was entangled in a few thread-like remains of clot, which kept it suspended in the vitreous humour, and allowed it to move freely backwards and forwards, while its movements outwards were checked by the body of the lens." We are reminded immediately afterwards that it is difficult to decide as to the depth of a body in the eye by means of the ophthalmoscope, so we ought not to take the forward and backward movements as being positively ascertained; and when we are told further, "it swung to and fro on a level with the equator of the eyeball," I take it we may understand that it was seen to oscillate laterally across the inner edge of the iris. This is just what the anterior fibres of the vitreous were doing at the same time.

We are next told that "the foreign body sunk backwards and disappeared when the patient lay down." He was knocking a hoop off a cask when the accident happened; and if we assume he was looking downwards at his work, the anterior bags of fluid had then preponderated to the bottom of the eye. On his putting himself on his back, the preponderating lobe of fluid became distributed over the whole bag, causing all the rest of the circumference of the layer of fluid to retreat from the lens in a radiating direction as regards the pupil, as well as actually to sink. Thus, were the chip entangled or impacted in one of the anterior septa, it would have made excursions about a mean position just as it was observed to do. Mr. Dixon's bold operation for the removal of the body needs no commendation, for it was attended with success.

I recapitulate the observations he has published, to endeavour to rouse attention to what I believe an important and new field of inquiry (undreamed of by him) in the study of ocular disease : that is, there are certain movements natural to the vitreous body ; if an object of any kind can be seen in this portion of a patient's eye, and we determine that its movements precisely correspond to those belonging to that portion of the vitreous where it is placed, we may conjecture that it moves with it, and not through it. If the fibrous structure of the vitreous become destroyed ("fluidity" of the humour), and clots of blood, flakes of fibrin or lymph, be suspended, or shaken up in it, these opaque masses will produce very different effects on vision, according as they are allowed to sink upon the most sensible parts of the retina, or down against the lens, or into the recess between it and the ciliary processes. Both the ophthalmoscope, and entoptical devices, and the ordinary laws of refraction within the eye, may all be brought to bear upon such an inquiry.

43. We owe the origin of entoptical methods of exploring the eye to the desire to unravel the mystery as to the seat and nature of the

objects that cause the phenomena of *muscæ volitantes.* I have, therefore, thought it more convenient to defer recounting their history until now, when I have to speak of the various speculations concerning these objects.

The most recent authority upon this literature is Helmholtz [Encyk. d. Physik, S. 163 (1856)], according to whom (omitting his citations of erroneous guesses) :—

"Dechales,* a Jesuit of the seventeenth century, first advances an opinion upon the origin of *muscæ volitantes*, and, indeed, the right one, that they are the shadows of corpuscles that swim in the vicinity of the retina. . . . Le Cat† describes an experiment which fully comprises in principle the method of entoptical investigation, inasmuch as he realized in a divergent pencil from a puncture the inverted image by shadow of a needle held close before the eye. . . .

"A more stringent theory of the phenomena, methods for judging of the places of corpuscles in the eye, were first of all established much more lately by Listing‡ and Brewster§, whom more lately Donders‖ followed. The latter's pupil, Doncan¶, then showed the correspondence between the objects seen entoptically and the microscopical structure of the vitreous body: James Jago ** attempted the same thing. Descriptions of the different forms of entoptical objects besides by those just named have also been given by Steifensand††, Mackenzie‡‡, Appia§§.

Out of the whole list of writings cited, Helmholtz marks two, Listing's and Doncan's, as being immediately consulted by himself. In one or other part of his article he extracts the whole substance of the former's Contribution to Physiological Optics, in which more than a page is devoted to a notice of *muscæ volitantes*, and which gives as a reason for so limited a sketch, that the subject had been treated of by Brewster ; and which then, in a foot-note, gives the long title of the last author's paper* in full. So we cannot doubt that Listing himself, at least, was aware that Brewster's claim to priority was indisputable.

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* Cursus seu Mundus Mathematicus. Lugduni, 1690, t. iii., p. 402.

† Traité des Sens. Rouen, 1740, p. 298.

‡ Beitrag zur Physiogischen Optik. Göttingen, 1845.

§ Transactions of the Royal Society of Edinburgh, xv. 377. (This citation the historian leaves undated, but overleaf he puts it under Listing's contribution as published in the same year.)

‖ Nederl. Lancet, 1846-47, 2e série, D. ii. bl. 345, 432, 537.

¶ De Corporis Vitrei Structura. Diss. Utrecht, 1854: Onderzœk. ged. in het Physiol. Laborat d. Utrechtshe Hoogeschool, Jaar vi. p. 171.

** Proceedings of the Royal Society, 18th Jan., 1855.

†† Poggendorff's Ann., LV. p. 134, &c.

‡‡ Edinburgh Medical and Surgical Journal, July, 1845.

§§ De l'Œil vu par lui-même. Genève, 1853.

From the words† quoted below, it appears that Listing's Contribution could not have been published until July, 1845, seemingly not until after that month; putting it, in all probability, later than the ninth paper quoted by Helmholtz. I have not had an opportunity of perusing this; but its author, in his fourth edition of "Diseases of the Eye," registers an essay ‡ of mine, published on May 9th and 16th of this very year, which possibly might have been the incentive to his publishing his own remarks on the same subject-matter.

I will here give, to the best of my ability, a critical history of the foregoing entoptical writings in their order of precedence. If, unheard of by me, anything like this has been already done, it will be none the less indispensable that a history of the sort should find place in this little work. I would have preferred that some one else should have undertaken an office not agreeable to me; but, having decided to undertake it, I feel bound to vindicate my own rights with an unflinching hand, though I hope never to pursue the shortcomings of others beyond what is needful for confining them within their own domains.

First of all, what has Brewster's celebrated paper accomplished for entoptics?

It is to be regretted that it was unaccompanied with diagrams. Had that not been the case, it could not have fallen to my lot at this late day to make the comments which ensue; for it would have been obvious what sort of entoptical conceptions lie at the bottom of his essay.

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* On the Optical Phenomena, Nature, and Locality of *Muscæ Volitantes;* with Observations on the Structure of the Vitreous Humour, and on the Vision of Objects placed within the Eye. I add from the Philosophical Magazine, January, 1848, where I have access to the paper as there reprinted from Tr. R. Society, Edin. :—Read March 6, 1843.

† Beitrag z. Physiol. Optik, S. 56. . . "ist erst vor Kurzen (im Juli 1845) enstanden."

‡ Points in the Physiology and Diseases of the Eye. By James Jago, M.B. Oxon. London Med. Gazette, 1845.

In his introductory remarks he tells us that De la Hire supposes the *muscæ* to be in the "*aqueous* humour rather than in the *vitreous*, because of its greater fluidity for a freedom of descent, and because they will then appear to descend, as being situated *before* the pupil, or, at least, *before* the place of intersection of the pencils." He does not point out the optical impossibility of a body in such a position throwing its image upon the retina in the naked eye; and, except that he casually mentions that with a divergent pencil the free fluids on the eye may to an incautious person perplex entoptical observations, he says nothing in general about the "vision of objects placed within the eyeball," or upon it. He only treats of the filaments of the vitreous. He opens his subject by telling us, without any reasons being assigned, that to see these objects distinctly, "we must look at the sky, or a luminous object, either through a very minute aperture, or, when the light is limited or feeble, through a lens or microscopic doublet of very short focus, held close to the eye." He places in this and his other writings the optical centre, instead of at C in Fig. 1, behind the crystalline lens, *appreciably* within the vitreous humour, and calls it the "centre of visible direction." He shall speak of the filaments himself. The italics are his own.

"All the bodies which we have now described have two different motions; one arising from the motion of the head or eyeball, and the other when the eyeball is absolutely fixed. By a toss of the head they are thrown into different absolute and relative positions, sometimes ascending and descending in succession, sometimes oscillating between two limits, and generally with different velocities. When the eye is first applied to the lens or aperture, the field of view is tolerably free of these moving bodies; but the light seems to stir them up, as it were, and, to a certain extent, the longer we view them the more numerous they become.

"If the centre of motion of the eyeball coincides with the centre of visible direction, the *Muscæ* will *ascend* when the eye looks *upward*, and *vice versâ*, whether they are placed behind or before that common centre. If the eyeball remains fixed, the *Muscæ* in *front* of the above centre will have the direction of their *real* and *apparent* motions the same, and those *behind* that centre will have these two directions *different*. Hence the appearance of two opposite currents when the eyeball is turned quickly from one extreme of its range, either vertically or horizontally, to its mean position."

This language is stringently explicit and methodical. The vessel moves, carrying with it its contents: that is, the head or eyeball moves. And the contents (whether head or eyeball has been moved) move in the vessel.

First, when the head moves: "By a toss of the head, they are thrown into different absolute" (they keep pace with the movement of the head) "and relative" (they change their places in the vessel) "positions." He makes the movements irregular, not perceiving, as I have pointed out, that a toss of the head is virtually a rotation of the eye, and causes like movements within this organ.

Secondly, when the eyeball rotates, for example, upward, the absolute movements of all the *muscæ* are upward, being carried with it, &c. When the eyeball is arrested in its movement, we observe their relative movements. Let any one read his statement and say whether his words can bear any other meaning than that the filaments in the anterior part of the vitreous humour actually move as they *appear* to do!! contrary to what happens with the posterior ones. As if, in keeping with De la Hire's notion, the rays of light that throw the shadows decussate at his optical centre of the eye, as the two lines *e* E and *f* F do in Fig. 1. As if, in short, he regarded the puncture, or the image of the light in the focus of the lens he employed, as an object of some magnitude (such as *e f* in Fig. 1), whose image the eye attempts to form by pencils of rays whose axes pass through the centre of visible direction, and which pencils cast shadows in the line of their axes.

It is palpable that he does not realize that the bodies rotate within the eye; but he fancies that they are all projected in one direction, and that the appearance of opposite currents is an optical illusion. In fact, his conclusion is that they are fragmentary bodies of less specific gravity than the fluid, floating within a few cells, clearly imagined to have virtually rigid walls, so that any movement whatever of the eye merely causes them to circulate or eddy about in their own cells.

But, to quote again: "Now it is obvious that, if we determine the visible position of the *Muscæ* when at rest in different positions of the head, we determine the direction of lines passing from the centre of visible direction through the points in the vitreous humour where the *Muscæ* rested, and thus obtain a general notion of the *form of the cell* in which it is contained." It is here asserted that the *musca* is seen by the retina in directions immediately opposite to those in which its shadow falls upon it. If we suppose Brewster to have conceived the radiating point to be, as above stated, an area of size imaged by centrical pencils which are the agents in casting the shadows, this sentence may be accounted for; but, as far as I can understand, not otherwise. Should we think that, inasmuch as he mentions in the previous page that a certain *musca* in his eye may be seen without a divergent pencil, this observation was made with the naked eye, it must be remembered that the hazy shadows of filaments in the vitreous thus displayed are (40) rather cast in the direction of lines that radiate from the centre of the *pupil.*

The author continues : "But we may go still further, and determine with considerable accuracy the diameter of the *Musca* or its filaments, and also their distance from the retina, and thus obtain a knowledge of its locality, and of the form of the cavity by which its excursions are limited.

"In order to do this, I place before the eye two bright sources of light, so as to obtain from them, by the method already described" (lens of short focus), "two divergent beams of light, and I thus obtain double images on the retina of all objects placed within the eyeball. The filaments or *Muscæ* in the anterior part of the vitreous will have their double images very distant: and those in the middle of it will have their double images much nearer : those near the retina will have their two images close or perhaps overlapping each other; while any object on the retina itself, any black spot arising from defective sensibility, will have only one image, as it were. Now, if we measure their distance from the centre of visible direction, when the two images of the filaments, &c., are just in contact, we may determine the size of the filament and its exact position, as well as its distance from the retina. In making this experiment, I first found that the angle of apparent magnitude of the shadow of the filament was 8 minutes, and, consequently, that it subtended this angle at the centre of visible direction. Now, if we take the radius of the retina as 0·524 of an inch, the diameter of the shadow of the filament will be 0·00122, or $\frac{1}{820}$th of an inch, and its distance from the retina 0·0118, or $\frac{1}{85}$th part of an inch."

In the absence of a diagram, it is unfortunate that the author did not, after all, give us a calculation of the diameter of the filament itself, as well as of its shadow; as this would have indicated his views as to the course of the rays for the pencil that threw the shadow.

Inasmuch as in the calculation of distance effected two of the data upon which it proceeded have been omitted to be mentioned, its principle could not be criticised until, in his capacity of reviewer,* the author much more recently supplied the missing numbers, namely, 5 inches for the distance between the two lights, and 49 for their distance from the "retina." We might suspect, from the last being measured from another point than the one announced, that he had not retained a note of his process, and that he may possibly now deviate somewhat from the original plan. But, assuming the steps of the calculation to have been in accordance with these numbers, we perceive that he finds the diameter of the shadow of the filament, with his optical radius, as is pointed out in 6. He then finds, it would seem, by the mode there shown, that, with his radius, the two lights so placed with the naked eye will have their retinal images 0·0541 of an inch apart. And since, as near as the number of decimals can write it, 0·0541 : 0·00122 : : 0·524 : 0·0118, it transpires that he assumes that the couple of rays from the pencils of light which project the shadow of the margin of the filament (no particular advantage accruing from having the shadows just in contact) and that couple that pass through the centre of visible direction are parallels (or, at least, nearly so).

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* The Sight, and How to See : North British Review, Nov. 1856, p. 172.

No objection could be raised against this artifice for finding the distance of the *musca* from the retina, had not one of the terms in the proportion been obtained upon an assumption which, unless I deceive myself, involves a grave fallacy: which is, that when we have determined the points upon which the retinal images of the two lights would be painted on the naked eye, we know the points at which those two rays of light that pass from the inverted images of the lights, formed by the lens close to the eye, through the point of visible direction (as if to cast its shadow), impinge upon the retina. If this be a trustworthy proceeding, a great deal of useless trouble has been taken in developing entoptical methods in our Chapter II. The axes of the two pencils that proceed from the two images intersect in the *middle of the pupil*, and by the other eye the apparent distance between the double images of the centre of the pupil may be measured; but this is not his thought.

That the members of each pair of shadows are further apart for objects further removed from the retina is a correct entoptical statement, but is not decisive, against other evidence, of the view the author took of the paths of the rays from a pair of pencils; for, in the examples he mentions, the statement would hold good if the rays that rendered the shadows crossed at or near the point of visible direction; because the anterior filaments would be nearer to this point than those in the middle of the vitreous, and the latter than those deeper in the eye. Whatever were his views, he could not help observing as a matter of fact that the relations he cites existed.

Immediately after the paragraph I last quoted, he tells us that the centre of divergency may be thrown within the eyeball, and placed at any distance from the retina. "If we wish to place this centre near the retina, a lens of considerable focal length must be used, and as the light collected by it will be powerful, it will extinguish all the smaller filaments and minute spheres, and allow only the larger *Muscæ* to be seen. We must, therefore, reduce its aperture by looking through a pinhole or other minute opening." The idea does not occur to him of turning the convergent portion of the pencil to entoptical account, nor does he seem to think of diminishing the area of the light or removing further from it to lessen its quantity. At any rate, it is surely a singular proposal to explore the regions near the retina with a divergent pencil in section *many times* smaller than the area of the pinhole. Such a contrivance in daylight would yield merely a pencil diverging from the hole; and, with a limited light at night, as many scattered rays from the room would diverge from it as would ever arrive at the focus near the retina to diverge therefrom. It may be appended that, though he eliminates *muscæ* from the aqueous humour, he does it on the ground that, did they exist there, they would, when the eye rests, either sink or rise out of view, and not by entoptically showing them to be posterior to the lens. As Brewster's paper has been esteemed, at least in this country, as marking an epoch in entoptical discoveries, I have thought it right to extract from it *every* remark he makes implicating an entoptical conception, that the reader may judge with me how far he had a well-defined and just method in his mind. It may seem to us incredible that a man skilled in and devoted to optical researches should have entangled himself in misconceptions merely geometrical; but it was not so unlikely at that time as it may seem to us now. It is a very simple thing to demonstrate that, when we look at a close object through a pinhole, it will appear to be magnified, or to occupy a greater angle than it spans at the optic centre of the eye: yet I remember its being taught, just before that date, by some who should have been best informed on such a point, that it was not magnified, as if its image were pictured by centrical pencils (with axes crossing at the optic centre), instead of eccentrical ones only crossing at the hole. In bringing this survey to an end, I hardly think I am wrong in venturing to doubt that Sir David's claim to having elaborated and *expounded* a correct entoptical method in this paper can be sustained, whatever might have been the real nature of his views.

But he specially treats of objects visible in the vitreous. Mackenzie had, he tells us, described "the *Muscæ* as resembling *minute,* *twisted, semi-transparent* tubes, partially filled with globules, which sometimes appear in motion," &c. He adopts this description, only discarding the idea of motion of globules within the tubes. Thus, though he was the first to observe that the images of the filaments are diffractive projections of transparent bodies, he did not perceive that these were simply produced by chains of nuclei, nor did he analyze any of the phenomena dependent on their different modes of aggregation, but makes many mistakes in details arising from this cause. Nor does he indicate how refraction takes its part in the production of the shadows.

Mentioning that Dr. Porterfield had before "given a very inaccurate drawing of the filamentous *Muscæ*," he gives us one of his own, consisting of several overlapping and intertwined coils of filament, from which issue four main branches in the midst of scattered circles. Taking in his postscript to the reprint of his paper, which I have before me, he has had this drawing under observation for about eight years; and on comparing it with the original, he finds that the knot or *musca* has been slowly increasing at the expense of the branches. This drawing, though probably unrivalled at the time, is but a rough approach to the truth; nor can one who has investigated the matter recognize in the coils a copy from the fibrous network of the vitreous; whilst the filaments (one excepted) he draws do not show any marks by which he might know a given length: they could have had no cut ends, and plainly he had no means of being assured that he always viewed them with like inclinations to the retina, &c.; and we may be sure he never could have measured the lengths. Hence the observations repeated at intervals are devoid of value, except it be, contrary to the author's opinion, to convince readers who have studied the subject that the filaments he watched had remained unaltered for so many years.

In spite of these drawbacks, it is much to have first directed attention to the diffractive phenomena of the filaments, to have ascribed them on strong grounds to the vitreous, to have noticed their opposite currents and different parallaxes, and to have formally proposed to determine their exact position and the structure of the vitreous by entoptical means.

I will now touch upon my own entoptical paper, which I have been so bold as to interpolate in Helmholtz's list. It is not to enhance its merits, but to account for some of its deficiencies, that I mention that it was written in ignorance that it had any such a predecessor as the above.

These investigations were carried on solely with light issuing from a punctured card held near the eye. It is at first shown experimentally that all bodies passed between the card and the eye seem to advance from the opposite side; and "that with a minute aperture, all the points in the field of view, except the central one, are seen exclusively by rays which cross the axis of the eye before entering it; so that in every section of the eye perpendicular to its axis each point is, as it were, set apart—made sacred—to a ray from a particular point of the field: hence, when a point in that section is opaque, its particular point in the field is unseen or dark—not the whole field slightly dulled, as without the card, for then each point (except for sections near the retina) receives a ray from all the points in the field." It is noted how the size of the image of a small body immersed in the cone of light issuing from the pinhole into the eye depends upon its position in it.

There are two diagrams in the paper. The first places the optic centre according with Brewster's views; the second was meant to have had a letter C to mark this point in it also, as is obvious from the context: but it is immaterial whether it is supplied or not. The figure accurately corresponds to the description given of it: it places *b* and *f* about a half-inch from the cornea; B on the retina; A, *a*, *m*, *h*, at indefinite distances beyond *b f*.

"Let the above figure represent a section of the eye through its axis A B; *a b c d e*, the course of a ray of light in this plane through the pinhole *b*, to the point *c* on the cornea, and, after traversing the textures of the eye, meeting the retina in *e; d*, any point in this line in the interior of the eye. Now, whether we suppose an obstruction to light to exist at *c* or *d*, or *e* to be insensible to light, a dark spot will appear in the same place of the field of vision, the angular distance of this spot from A C being determined by the distance of *e* from B.

"Again, let us suppose the pinhole to be shifted in a line perpendicular to the axis so as to be at *f*, join *f c*, and produce *c f* to *h;* then *h f c* is the course of that ray which now falls on *c;* and it is manifest that, since this line falls within *a b c*, its continuation through the eye, *c l*, must fall without *c e*. Moreover let *m f d n* be that ray which, entering through *f*, passes through *d;* it is plain that *f m* must fall within *f h* and *d n* between *c e* and *c l*.

"It follows, from the above reasoning, that if, when the card has its orifice at *b*, an obstruction at *c* would be dark on the retina at *e*, and that an obstruction at *d* would be dark at the same point, and that the card be removed so as to have its orifice at *f*, the obstruction at *c* would be dark at *l*, and that at *d* would be dark at *n*, so that *n* is without *e*, but not so far as *l* is. Hence, the further from the retina the obstruction is that causes the obscurity in the field, the further will it appear to move on a given cross movement of the card." And, after having applied this general proposition to the different ocular structures *seriatim* from the retina to the cornea, I add, "though these variations according to distance from the retina do not follow the law of proportion."

"Again, inasmuch as the size of the cone or pencil of light which enters the eye from the pinhole is determined by that of the cornea (or, at least, the assertion is near enough to the truth for my purpose) [I had premised that I should "suppose the pupil to be dilated to its maximum"], or, in other words, the cornea is the base of the cone, it follows that the place in the field of view of the shadow of an opacity in that part will remain the same for all positions of the hole: hence the shadow always seems to move exactly with the hole, as if its cause were fixed in it. Thus, the fluid on the conjunctiva might make us imagine that the card had not been punctured clean.

"The shadow of anything outside of the eye, as that of an eyelash, moves faster than the hole, or rather the apparent motion of the hole."

I then repeat the story for two holes in a card held at rest before the eye, and again, speaking of the pupil as the strict base of the cone of light, go on to observe that, by "observing how many graduations or degrees the obscurity passes through on a given number for the card (or a given distance between two holes), we might, were we so disposed, make very nice calculations as to the exact place in the eye occupied by a small obstruction projecting a shadow on the retina; that is, supposing we knew the exact indices of refraction and other optical conditions of the different media of an individual eye; all the data for such a calculation being then present." That is to say, something nicer might be accomplished than by assuming the above *variations* as proportionals; but I disclaimed any intention beyond showing in a practical way how to find in what structure a given obstacle to light resides.

It must be borne in mind that the *purpose* I had *immediately* in view was to solve the question of *muscæ volitantes*, and that from my unwittingly carrying on my examination of these bodies in the vitreous with punctures insufficiently small, I altogether overlooked the anterior cross current. The see-saw motions of the *muscæ*, if seen, must of necessity have been regarded by me as *real* opposite movements, and I should, doubtless, have been impelled to apply the principles I had evolved with all their stringency. As it was, remarking—"If we employ a card with two holes, and get a *musca* within range of both, we shall find that even for one which throws its shadows at the greatest distance from each other, the angular distance between the shadows does not even approximate to that between the centres of the two holes as they appear in the field of view (not reaching one-eighth of the distance in my own case)"—I regarded the answer to be arrived at, resting between the aqueous and vitreous fluids, as so widely removed from the possibility of mistake, that I thought I might as well look upon the pupil and cornea as lying in coincident planes, and compare the places of the *muscæ* with the easily recognizable tears. I concluded—"Hence the *muscæ* are not far from the retina, and are far from the cornea: also they are in a fluid. Therefore the vitreous is, of necessity, their seat."

This I believe to be the earliest instance of the employment of the *comparative* entoptical method. It may appear to be a somewhat rough proceeding ; but, fundamentally, it is as accurate as any in use before the introduction of the convergent pencil. For, as we can directly measure the parallax of a tear, it is superfluous to imagine the iris to be removed that the cornea may be the base of a cone of rays; and as no appreciable refraction takes place between the cornea and the crystalline lens, we get an equally just measurement of the place of an entoptical body by comparing its parallax with that of a tear as with that of the iris.

I submit that there can be no question that my paper gives an exposition of a true entoptical method, and, in the midst of its oversights and faults—and, let it be admitted, thoughtless blunders,—the rudimentary notions of the causes of the movements observed in the *muscæ*, put forward by it, may bear comparison with any preceding it. "When the eye is brought to rest, they, by their buoyancy, or, what is far more probable, by the recovery of its original form and place by the vitreous humour brought about by the connexions of the hyaloid" [membranes springing from the hyaloid to form septa] "membrane, and of the elasticity of neighbouring parts, rise again to their original places, and thus appear to sink." . . . "There cannot be anything like free motion in such a cell-divided fluid." . . . "The more I consider their connected chain-like character, their figures remaining always extended, their branches thrown out in so many different directions, and to such great lengths, the different parts of their figures changing their relative positions but very little, so that each *musca* has, so to speak, a home in the vitreous, to which after each disturbance it finally returns, the more I feel disposed to regard them as fringes or processes of the hyaloid" [dissepimental] "membrane, or as deposits in it. In this case increase of these may result from inflammation of this membrane."

I reproduce this view of the nature of the *muscæ* because I am convinced that, if allowance be made for the defective information existing at that time with respect to the histology of fibrous tissue, it will be found virtually more correct than any proposed by other entoptical writers up to this day. The paper insists that the causes of the *muscæ* are *essential* to the idea of the vitreous humour, if we include the septa in that term: and, had it not contemplated the *bare* possibility that pathological *muscæ* might occur like the physiological, even its nosological comments might still pass muster.

I suspect that the *ninth* paper in the list of quotations, that by Mackenzie, was the next that was offered to the public; but his entoptical claims cannot be invaded by our taking Listing's next.

Instead of moving the puncture, as I had done, across the optic axis, he produced the same relative movements by rotating the eye across the puncture. In finding the retinal distance between the lines that project the centre of the pupil on the retina by observing the angle swept through in the field of view by the optic axis, he did no more than regard the pupil as the base of the cone of light, and therefore its centre, as moving (as I characterize the fact) "exactly with the hole;" and in regarding the two lines that project the pupil as proportional to those that project a point in an entoptical corpuscle, he did no more than accept as proportionals the very lines that I had noted as not so. The scheme he adopted for the measurement of ocular depths is, in every respect, similar to that which I used for collating such depths. Even his idea of negative and positive parallaxes with respect to the pupillary plane is virtually contained in my remark on the movements of the shadows of the eyelashes.

When Donders observes with two punctures the angle subtended by the duplicate image of the margin or centre of the pupil, and also that of an entoptical object, in order to employ the same proportionals as Listing in investigating the *fluid* vitreous, he virtually does precisely what I had done before him. Doncan deviates from this mode merely in marking the angular distances with the other eye.

However, these three writers preceded me in attempts to actually measure the sizes of various entoptical objects, which I find to have yielded results that do not differ widely from my own: and Listing's Contribution has proved of great use to me from the skilful way in which he has discussed the question of the optical centre of the eye.

I find from Helmholtz,* who quotes Doncan, and who, no doubt, in his turn had quoted Donders, that he and they had all taken great pains to scrutinize the vitreous entoptically. They state the general character of the movements of the filaments in the vitreous with greater accuracy in some particulars than had been done before—observing that they remain steady when we look up or down, and do not approach the then upper wall of the eye, though they are specifically lighter than the fluid. Also the movements or rotations of the eye in different directions, though some nicer ones be overlooked, are described in a more correct way. They take the opposite currents as facts. They move thus, says Doncan, and he is quoted with approval, because some lie behind and some before "the centre of rotation of the eye" (dem Drehpunkte des augen liegen); not the middle of the vitreous, as I affirm, and thus they did not conceive the idea of embracing under one description all the ocular movements. No consideration is given to the effects of diffraction and refraction of the fibres, and therefore the optical observations could not fail to be erroneous; but it is certainly curious that a man so accomplished in optics as Helmholtz should carelessly admit the possibility of seeing folds of membrane in the vitreous, "in the shape of bright ribbons, bordered by a couple of darker, not sharply-marked lines." In short, the most of the analysis of the optical phenomena is little more trustworthy than the general conclusion, that they are indicative of the remnants of a fœtal cellular structure of the vitreous, some of whose rags still hold to the hyaloid, and some float at large in the fluid,—than which all are specifically lighter.

Mackenzie, in his fourth edition, in appending a long list of authorities, often neglects to tell us what observations were theirs, so that one cannot feel sure whether a given idea originated with himself. But this being the only book by another author in which I have met with the employment of a convex lens of sufficient length of focus for carrying this point deep into the eye, for the purpose of judging, by the reappearance of an intra-ocular body in an *erect* aspect, of its distance from the cornea, I give him credit for having been a considerable contributor to practical entoptics.

However, he does not even allude to the inversion of shades that the entoptical images thus undergo, and without attention to which they are no longer recognizable. He calls the optical centre of the eye its focal centre, and it is dubious whether he did not fancy that the position of a body with respect to it affects its visibility in a single convergent pencil. At p. 952 he treats of a pair of such pencils, obtained from two candles, and plunged into the eye by means of a lens of 1½-inch focus, when he makes the double images of a tear stand more widely asunder than those of threads in the vitreous so much nearer the foci, &c. ! His whole handling of the subject evinces that he had not, if one may so speak, worked out their geometry.

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* I had published my Ocular Spectres and Structures as Mutual Opponents before Helmholtz's article appeared, and might claim the priority of him in certain points; but when it is dubious whether the observations are his own or of one of the other authors, I presume them to belong to one of these. I ordered a copy of Doncan's Dissertation, but it has not come to hand.

Nor did he understand that of divergent pencils. He mentions my paper, and, I believe, makes use of it; yet, in spite of its clear diagrams showing the paths of the rays, led away by the authority of Brewster, he actually volunteers a diagram to show how, in these pencils, the real motion of *muscæ* situated before the focal centre of the eye corresponds with the apparent, whilst behind the motions are contrary to each other. The diagram merely consists of a couple of lines drawn from the retina through Brewster's centre of visible direction and prolonged into space; and, to have greater room for illustrating his subject, he indicates, of all places, an anterior body as if having moved along the diameter of the pupil; in which position it would never, in the ordinary way of using the eyes, define itself on the retina; so that the diagram does not admit of the defence that he meant to speak, in this instance, of vision with the naked eye, and not, as he had been doing, of vision with divergent pencils. This diagram is interesting, as evincing the sense in which one who had conversed on *muscæ* with Brewster apprehended his words.

He adduces (p. 951) Brewster's proposal for measuring the size of the retinal filament, without objecting that the promise is not kept, and for estimating the retinal distance, without a word on the absence of certain of the announced data. Helmholtz (op. cit. S. 162), (who, we must infer, copies from an intermediate writer) speaks thus on this subject:—"In order to measure narrowly the distance of an object floating in the vitreous body from the retina, first of all has Brewster hit upon a method in which he let two pencils of homocentric rays enter the eye, and through them obtained two shadows of every object. From the distance of the shadows from each other, can be found the distance of the object from the retina. Brewster to this end looked towards two lights, placed near each other, through a lens placed before the eye." Thus Helmholtz slurs over the conditions of Brewster's proposition in such a way that no one can conjecture its precise nature; yet he goes on to give every particular of the plan pursued by Donders, &c. Hence, altogether, I am corroborated in my opinion that, both in this country and abroad, Brewster's paper has escaped unchallenged,—by the many readers because they had not the elementary knowledge requisite for understanding the subject, and by those who had such knowledge, because, unable to realize in their minds that the author could have erred in such an investigation, they were induced, as an alternative, to suspect themselves of dulness in catching the import of his language,—perhaps, in some instances, in strictly understanding a foreign language. In this country no other person versed in optics has worked at entoptics, and Brewster, having been for long our sole popular writer on optics, has naturally swayed the minds of the medical public on such matters. The numerous minute details of the phenomena produced by bodies in the vitreous registered by Mackenzie are valuable contributions, because they help to make good the fact that they are common to the human eye. But, sown among many pertinent remarks on the *muscæ* by the distinguished oculist, so many fanciful errors (to say no worse) in optics are met with, that his inferences are of little worth.

The woodcuts in Helmholtz's article, representing the filamentous and membranous appearances of the vitreous, are very indefinite: but those writers no longer talk of the concatenation of circles as projected by bodies enclosed in tubes. Mackenzie directly states that the appearance may be due to diffraction; though he yet imagines that certain parallel shadings are images, not of fibres, but of obliterated vessels once feeding the vitreous from the central artery of the retina. There is in his book, also, a delicately-executed plate, which copies, in a divergent pencil, strings and groups of circles, with here and there some more strongly marked; besides scattered circles and white stripes with grey margins. Nevertheless, by carefully putting black dots as centres to many of the little white circular areas, quite incompatible with their mode of production, he betrays that he had not analyzed their character. He regards all the figures as indicating fragmentary or free bodies.

It was shortly after the date of his book that I resumed my entoptical studies. Crude as one or two of my enunciations may have been before I arrived at my mature views, I think I may safely affirm that, whilst all other entoptical writers have cherished the notion that the adult vitreous is a wreck of a former state, I have always insisted that its fibres constitute an unbroken network. It was in the Medico-Chirurgical Review, 1859, that I first conceived the idea of a varying specific gravity in the fluid; the key, as I hold, of the entoptical mysteries of the vitreous. I have given to other writers, to the best of my information, full merit for their contributions, and I must leave to the discrimination of the reader to say whether I have advanced the study in any ways not particularized.

With the Babel of medical literature on *muscæ volitantes* my readers shall not be afflicted. I have only turned for this account to three systematic writers on disease as likely to be among our safest guides on such a subject. I will confine myself to saying a few words on some statements they make, in the midst of sound remarks, which I think likely to mislead the unwary.

Mackenzie avers (p. 956) that eyes that are subject to *muscæ* are always either "myopic or prebyopic," because an accurate refocalizing of light, issuing from external points, upon the retina prevents their being projected thereon. The optical reasoning is absurd, and I am confident, from very extensive inquiries in these phenomena, that the statistical fact is unsupported by experience: though in my earliest essay I pointed out that persons who fancy their sight to be failing are more apt than others, from their solicitude, to have their attention arrested by the accidental phenomena of vision.

Dr. Watson (Practice of Physic, vol. i., p. 354), whose mathematical acquirements should render him peculiarly competent to speak accurately on the phenomena, puts himself implicitly in the wake of Brewster with respect to them (as in N. B. Review); and reproduces many of his errors. Finally, he disposes of the subject in this perhaps (40) too pithy sentence:—

"The simple and easy criterion, then, is this. The *muscæ* which are motionless when the eye is at rest, and move with it when it is in motion, are signs of danger to vision. Those which sink gently downwards when the eye is fixed are innocent."

Dixon (Holmes' System of Surgery, vol. ii., p. 767) refers his readers particularly to Mackenzie's writings, mentioning also my Ocular Spectres and Structures as Mutual Exponents, as demonstrating the harmlessness of these *muscæ*. He singles out shortsighted persons as those peculiarly liable to them, but does not attempt to explain why.

CHAPTER VI.

THE RETINA VIEWED ENTOPTICALLY.

44. Behind the fibrous tissue of the vitreous body, we meet with other objects which light renders visible entoptically; the chief of these being (3) the central vessels of the retina.

The arteries we may see in diffused daylight with the naked eye *at rest*, but not the veins; for it is only when the images of these objects *move* upon the retina that they are discernible.

We have now come across the first instance in which our entoptical researches have led us to notice one of a series of phenomena whose cause must be inherent in the *sense* of sight, and which intimate that there is a law of sensation by which the retina ceases to be aware of the presence of certain images if they fall for more than an instant on the *same* sentients.

At each contraction of the left ventricle of the heart, the swelling-out of the arteries of the retina is visible. In considering this movement, let us remember that length and velocity in the retina, when referred to an external surface, are vastly multiplied; insomuch, that if the surface we gaze upon be only distant five feet from the eye, the apparent amounts to one hundred times the real. Hence, without allowing for the lingering of each sensation of light, the progress of the merest drop of blood may show itself as a more or less continuous line. Let the eyes rest steadily towards the sky, then a pulsation will announce itself, in many places, as a grey, dun, or darker round spot, beginning at a point, and dilating to a certain size; whilst around this spot will appear an areola much brighter than the sky, beginning as a small ring, and enlarging as the spot expands. See Fig. 45.

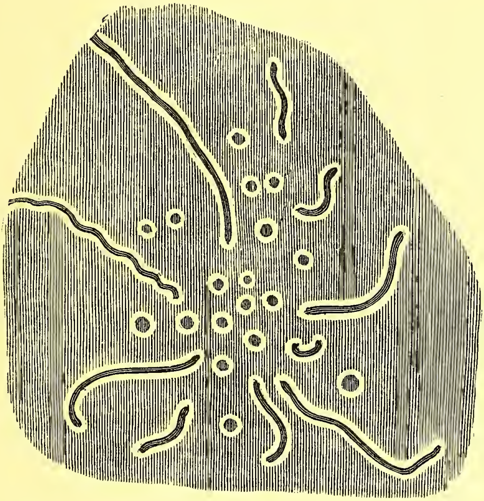

FIG. 45.

We also notice long portions of vessels exhibiting themselves in a similar style with the phenomenon now described; as the blood swells through them, simulating shorter or longer grey bodies, tortuous or serpentine—phosphorescent along their sides and ends—cleaving the air. By resorting to the expedient of moving pencils of light, to be spoken of shortly, one can in a moment determine that the phantoms are due to the said arteries.

Objects so near to the possible limits of the position of the sentient surface could not display a diffractive fringe of the breadth of the illuminated border: which is also unaccompanied by any dark fringe; and the image is not thrown in a single pencil of light, but by light issuing from the pupillary window (40). Hence what we see can only be shadows of opaque or semi-opaque bodies that reflect light from their sides, which falls upon the surface that sees them close to the shadow, thus indicating the nearness of the body to this surface.

In the manner of production of this shadow we may seem to have some evidence that the sentient surface of the retina lies behind the arteries. Because it is conceivable that with a sentient surface in front of them, whose sentients *face backwards,* shadows cast in a single pencil of light might, by reflection of rays, parallel, or nearly so, from a posterior smooth surface, be cast upon particular sentients, so as to be seen definitely; yet it is not conceivable that shadows yielded by the illuminating pupillary window would be nicely reflected upon such sentients. However, a surface posterior to the vessels, of a granular character, may be so illuminated from the pupil as to radiate light in all directions, and thus itself be the means of casting the shadows of vessels forwards upon such sentients. So we will not consider the question of the anterior or posterior position of the vessels with respect to the sentients as settled by this phenonemon.

Nevertheless, it may be subjoined that, according to Helmholtz's article on Entoptics (Encyk. &c., S. 160),

E. H. Weber calculated that the stoutest branch of the vena centralis, $\frac{1}{500}$ of an inch, is not wide enough for the nucleus (umbra as distinguished from penumbra—see Fig. 45) of its shadow, as cast by light from the pupillary window, to reach the back of the retina. Such a deduction must be more decidedly true of the narrower arteries whose shadows *are seen* with the naked eye. If we knew the exact dimensions of a particular vessel, we might arrive at a notion of the distance of a sentient surface seeing it from behind, by observing the breadth of the shadow. Or we might do the like, by observing the breadth of the reflective border. Such calculations would be obviously very simple; but we are liable to so many sources of error in fixing the data for making them, that I shall pass on to others of a less objectionable sort.

45. In resuming the use of the divergent pencils of light, we find that though up to this time we have advantageously, as one means, practised our observations upon the images projected whilst they remain ocularly steady, the results to be earned by such method in the example before us are nugatory ; for it seems fruitless to search for a pair of shadows of any vessel in a couple of divergent pencils.

We are in condition to proceed, however, for by 17 we have an artifice which elicits these shadows with singular precision. When divergent rays impinge upon the retina from some point in advance of it, and we impress this point with a lateral motion with respect to the retinal surface illuminated by it, the shadows of all the vessels which are at right angles to the direction traversed by the point become conspicuous, and may, by great excursions of the point, be plainly detected making small excursions of their own *in the direction in which the point moves*, similarly to the conduct of the objects next them in the vitreous humour, but to a much less extent; intimating by the deviation that the vessels figure themselves by true shadows, which are received upon a screen at a certain distance from their own site. Indeed, whilst the said movement is inoperative for bringing such portions of the vessels as are parallel to it into view, the slightest degree of it suffices for those at right angles. But no sooner is the movement stopped than the apparitions summoned forth become latent again. Wherefore, if the point be made to describe a circle in a plane perpendicular to the optic axis, so much of the *vasa centralia* as occupy the illuminated portion of the retina will be completely disclosed, as in their turn all will be *crossed* as required.

Or, to speak more accurately, owing no doubt to some portions of the capillary loops overriding others in the direction of the impinging rays, very commonly one portion of the loop presents itself rather than the rest; or the knots where branches unite display themselves, from their greater breadth. In order to convey an idea of the appearance yielded, I have endeavoured in Fig. 46 to copy the general style of the ramifications surrounding the *punctum aureum* of my right eye, as projected upon the paper, with the origin of the vessels to the right, which are shown as issuing from one root (a venous trunk), that the reader may not be misled into fancying that I profess to have bestowed so much perseverance on this sketch as to have laid down the separate courses of the veins and arteries. The drawing (3) is about twenty-five times the breadth of the retinal original, which corresponds to viewing the figure (6) at fifteen inches from the optic centre. This we may do by looking at a ground-glass globe of a lamp placed at that distance, whilst we cause a puncture in a card to revolve, within the circle of the pupil, round the axis of the eye. The capillaries, which are only introduced into a patch at the middle of the figure in and about the *punctum aureum*, are then discerned as minute dots. Against a remote surface, as a white cloud, they appear more like Fig. 47. Both veins and *arteries* (these being visible both collapsed and full) are kept in

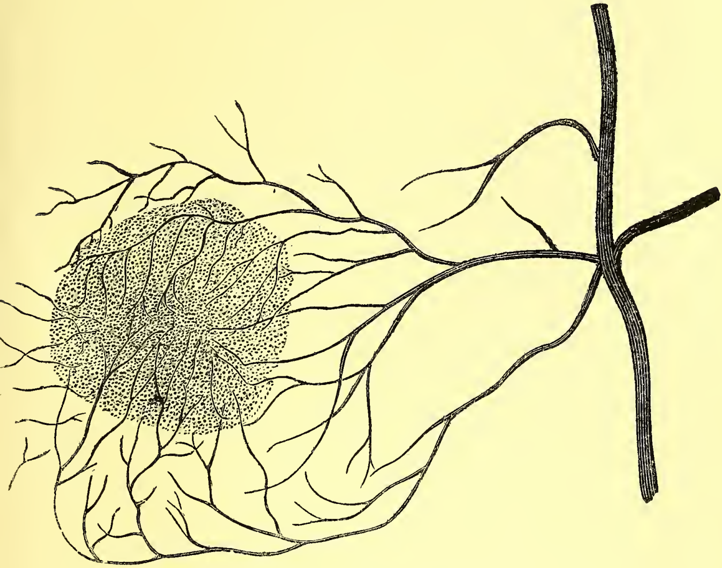

Fig. 46.

view by the means employed, and wear reflective borders, as in Fig. 45; though thesehave been omitted in the accompanying drawings.

I am positive, too, that I do not deceive myself in believing that I detect a subtle black ring round each of many of the capillary dots which fall upon the more sensible portions of the retina. This diffractive fringe could not be shown in a woodcut, where the dots themselves are probably as large again as the originals at the fifteen inches. In no instance do I get in a dot a glimpse of a central brightness from inflection; though this does not prove that there may not be such a brightness too little to be visible. I see no sign of the external black fringe by the side of the large vessels, possibly because it is extinguished by the powerful reflective border. The inflective facts as regards the capillaries manifest that they do not touch though they very nearly approach the sentient surface.

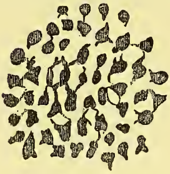

Fig. 47.

It will be observed that I have dotted the whole middle of the figure, without leaving a vacant circle in the region of the *foramen centrale*, which many call the spot without vessels. I have done this, because very tiny dots, exactly like if smaller than those of the circumjacent capillaries, do appear to span the region of the hole, so as to leave no break in the capillary network. The presumption furnished by this experiment is that this spot is penetrated by excessively fine capillaries of this system of vessels. The dotted appearance is not peculiar to my eye. H. Müller sees the like, and regards them as shadows, though not of vessels. Helmholtz, in speaking of observations upon these shadows through a punctured card, says :—"We see in the vessel-less place, which with me seems to have a finely granulated aspect, and in which a round shadow moves about with the movement of the opening, &c." The dots I regard as undoubted shadows; and until the microscope has discovered another cause, it will be hard for me to persuade myself that they are not vessels. However, it were better not to look upon Fig. 45 as sketching, among others, arteries in the foramen, as I do not feel sure that the smallest capillaries can be seen to pulsate.

Now, as a parallax attends the apparition in its maintenance by perpetual movement, the essential condition of the phenomenon must, as Wheatstone propounded, depend upon the fact of the shadow being ever thrown upon *fresh* sentient points.

46. Purkinje, to whom we owe these expedients for conjuring into view the vascular phantom, has bequeathed to us another striking one, the same in principle, though demanding a special explanation. This is that of waving a lighted candle before the face.

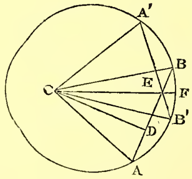

FIG. 48.

Let us suppose (Fig. 48) A B A′ to be a section of the sentient surface of the retina by the plane of the paper, in which the optic axis falls, and C to be the lenticular centre of the eye. Let A B and A′ B′ be equal chords of the circle cutting each other in E. Draw C D perpendicular to A B, and join by straight lines C with A, A′, B, B′, and E; producing C E to meet the circumference A′ B A in F.

Then $\mathrm{EF} = \mathrm{CF} - \mathrm{CE}$. But $\mathrm{CE} = \dfrac{\mathrm{CD}}{\cos \mathrm{ECD}}$. And $\mathrm{CD} = \mathrm{CB} \cos \mathrm{BCD}$, whilst $\mathrm{BCD} = \frac{1}{2}\,\mathrm{ACB} = \frac{1}{2}\,(\mathrm{ACF} + \mathrm{BCF}) = \frac{1}{4}\,(\mathrm{ACA'} + \mathrm{BCB'})$. Again, $\mathrm{ECD} = \mathrm{BCD} - \mathrm{BCF} = \frac{1}{4}\,(\mathrm{ACA'} - \mathrm{BCB'})$. Moreover, CB, very nearly $= \mathrm{CF}$. Hence, if $\mathrm{ACA'} = \alpha$, $\mathrm{BCB'} = \beta$, $\mathrm{EF} = d$, and the optical radius $= r$, the equation first given becomes

$$d = r\left\{1 - \frac{\cos \frac{1}{4}(\alpha + \beta)}{\cos \frac{1}{4}(\alpha - \beta)}\right\}. \quad . \quad . \quad (1)$$

Acquiescing implicitly for the present in the hypothesis that the vessels are in front of the sentient surface, if A be the retinal place, at a given instant, of the image of a candle-flame which is being waved laterally before the eye to keep the vessels in sight, and E the place of some vessel; then B, found by joining A E by a straight line, and producing it to meet the surface, marks the point by which E will be seen. Then, should we carry the candle round to the opposite side of the eye, so that the shadow of E, whose position is supposed unknown, deviates equally, twice in one plane, that in which the optical centre of the eye and the two resting points of the flame lie, then B′ will mark the sentient place of the second shadow. Then, if we observe the whole angle, α, between the two resting points of the flame, and the angle, β, between the pair of shadows, we can determine the distance, d, of the vessel from the sentient surface. For example, let $\alpha = 96°$, $\beta = 4°$, $r = \frac{3}{5}$ of an inch (6), then $d = \frac{1}{108}$ of an inch, as is easily found by aid of a table of natural cosines. If we observe the two positions of the flame, or of the shadow of the vessel, in the field of view, we may, by bisecting the angle A C A′, or B C B′, dot down the site itself of E.

Thus, in ordinary language, when we hold the flame below the eye, the capillary patch at the punctum aureum will appear above any objective point upon which we gaze directly, revolving round it with a notable parallax as the flame encompasses the optic axis, receding from the point should the flame approach the axis, and *vice versâ;* the shadows of all the other vessels appearing in accordance with the plan of finding their places, as above expounded. So that it is indisputable that the shadowy figures of the vessels are projected by rays which diverge by reflection at the site of the image of the flame in the back of the eye.

With other conditions the same, the parallax is greater for a vessel more removed from the sentients. The principles of 12 and 17 apply here generally, the divergent pencil falling upon the vessels from very obliquely situated points, yielding much deviation of the shadow from its perpendicular retinal projection; the screen thus, too, becoming further separated from the object as the radiating image of the flame approaches it. So, as the candle travels about, do we see any two vessels, which decussate one over the other, glide across each other from a consequent difference in parallax. Also the relations between the positions of the radiant point, the body and the screen (with an allowance for its obliquity), and the size of the shadow (11), hold good here also; whence the broad shadows afforded by a vessel when in the vicinity of the image of the flame. Were we, in Fig. 48, to join A and A′ by a straight line, and draw a tangent at F, and produce A B and A′ B′

to meet it, we should obtain a figure similar to so much of Fig. 7 as has reference to two divergent pencils (12), and we might use the equation given in connexion with it for finding the distance of E from the tangent, and thus at no great labour, as we know the size of the eye, get *d*.

47. The same experimenter has taught us that the vascular tree may be rendered clearly visible by light admitted into the eye through its coats. If we concentrate the light of a luminous disc, say of the sun, upon the sclerotic coat, by means of a lens of short focus, the rays, penetrating all the coats, will radiate over the retina; and if the focal point be carried about over the white of the eye, particularly as far back from the cornea as is practicable, the shadows of the vessels will be projected, precisely as in the preceding experiment. To see them most distinctly, the eye should look upon a dark or shaded ground. This will, through the absorption of other colours by some one or more of the ocular tunics, assume more or less an orange hue, and the reflective borders of the shadows brightly display the same.

In this case, the lens moves with the retinal image. Thus, when it concentrates light below the cornea, the capillary patch at the punctum aureum will appear *below* any objective point upon which we gaze, and will revolve apparently on the same side as the lens, as this circulates round the cornea. It is palpable that Fig. 49 is equally adapted for this proceeding; and the calculations of 46 will also be available if observations be made from two foci diametrically on opposite sides of the cornea.

48. Yet, again, let A B (Fig. 49) and A′ B be two equal chords of the outer of two concentric circles, in the plane of the paper, in which the geometric and optic centres of the eye are assumed to lie, and cutting the inner in E′ and E respectively; C the eye's optic centre; and C D perpendicular to A′ B. Draw the straight lines C A, C A′, C F, C F′ and C B. Then, as for Fig. 48,

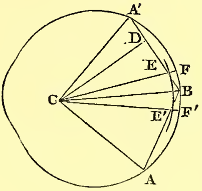

FIG. 49.

$$\mathrm{E\,F} = \mathrm{C\,F}\left\{1 - \frac{\cos\frac{1}{2}\,\mathrm{A\,C\,B}}{\cos(\frac{1}{2}\,\mathrm{A\,C\,B} - \mathrm{B\,C\,F}}\right\}.$$

Or, using the same notation for the angles, and for E F, as for Fig. 48, but calling C E, r, instead of C F, we have

$$d = (r + d)\left\{1 - \frac{\cos(\frac{1}{4}\alpha}{\cos(\frac{1}{4}\alpha - \frac{\beta}{2})}\right\}; \text{ whence}$$

$$d = r\left\{\frac{\cos(\frac{1}{4}\alpha - \frac{\beta}{2})}{\cos\frac{1}{4}\alpha} - 1\right\} \quad . \; . \; (2).$$

If E E′ indicate a section of the sentient surface, and F B F′ a section of some tunic without it, and light radiating from the image of the flame A were to cause the point B in the tunic to be seen by being there reflected, E is the point by which we should behold it, and B C F the parallax. If the image of the flame rest at A′, similarly, B C F′ will be the parallax.

Glancing from equation (2) to its fellow (1), and remembering that β is comparatively small, it is plain that the fraction involving the cosines in the former instance must be a very little less than unity, whilst in the latter it must be a very little greater, so that for the same observed angles α and β, the two equations must give values of d not differing appreciably from each other.* So that, altogether, the conception of an exterior point, B, being seen by a second reflection of the rays from the flame, demands for it a parallax difficult, if not impossible, to discriminate from that of a vessel placed just as far interior (speaking in terms having sole reference to the eyeball) to the sentient surface.

There is a phenomenon, which if not an example of the kind imagined, closely simulates it. For as the flame is brought near the optic axis from a lateral position, so that objects lying by the latter may reach their greatest parallactic deviation, the middle of the vascular effigy acquires a grey complexion: and if, during a few seconds, we whirl the flame with somewhat of briskness round the eye, an abruptly-defined, dark, quite circular area, whose diameter subtends with me just 4°, as if from a sentient circle of about $\frac{1}{25}$th of an inch in diameter, comes forth; and as the flame travels round the optic axis, doing the same on the further side of it in such a way as to show that the axis passes through its cause's own centre. In a word, it is made evident that the phenomenon is co-extensive with the foramen centrale (3), and is begotten by it; and recollecting the circumstance that the fovea is *par excellence* the retinal spot that suffers the pigment of the choroid to be visible from within, and that it has been demonstrated (46) that it is by the rays of light reflected from the internal periphery of the eyeball that the vessels are revealed, we instinctively ask ourselves whether the pigment could be seen as conjectured in Fig. 49. And observing that the mean capillary patch, sweeping over the pigmentary circle, enjoys about half as much again of the scope of angular freedom that the said shady area does, we consider, whether we should assign, from equations (1) and (2), the sentient surface, an intermediate position to them and it.

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* If $\alpha = 40°$, and $\beta = 4°$, equation (1) gives $d = 0{\cdot}0037$ of an inch, equation (2) gives $d = 0{\cdot}0033$ of an inch.

49. However, if we adopt the opinion that the sentient surface is exposed to be excited by lucid images conveyed to it from rays traversing it centripetally, we allow that there is, *primâ facie*, no improbability in the hypothesis that the very shadows of the vessels inspected by us may be the reflection of shadows previously cast outwardly upon a surface enclosing the sentient one; and so, whether the last be located without, at, or within the vessels.

If the reader, in imitation of the style of Figs. 48 and 49, will draw four concentric circles near together, and consider the outmost one an axiform section of a reflecting mirror A B A′, and the other three of sentient surfaces, passing severally without, through, and within the vessel E, whose shadow is cast by the ray A B upon the mirror at B, and reflected in B A′, which cuts the three sentient circles in e', e'', e''', indicating the parallaxes F C F′, F C F″, F C F‴, then it will be obvious that these parallaxes fall all in the direction of those which we actually witness in the vessels, and that these angles are greater, first as E is further from the mirror, and secondly, as the sentient circle is further from these. In the case in which E and e'' are in one circle—the surface in which the vessel is imbedded receiving its reflected shadow posteriorly at another place—we may simply by writing $\frac{\beta}{2}$ for β in equation (1) find d, the distance of either sentient or vessel from the mirror, or

$$d = r \left\{ 1 - \frac{\cos \frac{1}{4} \left(\alpha + \frac{\beta}{2} \right)}{\cos \frac{1}{4} \left(\alpha - \frac{\beta}{2} \right)} \right\} . \quad . \quad . \quad (3)$$

And we have only to imagine the radii of the sentient surfaces supposed to lie within or without the vessel to vary, in order to diminish or increase this value so as to approach the value of d as estimated from equation (1).

Though it is true, then, that the trials of equation (1) upon variously-disposed vessels in our own eyes will be found to accord very well with the hypothesis upon which we started, that the sentient points are a little external to the vascular plexus, within the limits of their known distances from the choroid, we can scarcely feel so sure that our mode of estimation is so conformable to the conditions of the standard—much less of an individual eye—or that the angles to be observed can be so reliably taken, as to entitle us to neglect the possibilities of other textural super-impositions, as hinted at by equations (1) and (3), backed by the spectral intrusion of the *foramen centrale*. We should not, without some hesitation, decide between the following arrangements :—

a. The sentient surface without, the *cause* of the dark figure of the foramen, and the vessels, both casting direct shadows.

b. The sentient surface between, receiving the direct shadows of the vessels, and the reflected rays of the foramen.

c. The sentient surface within, at, or without the vessels, and receiving their images and that of the foramen, by reflection.

d. The sentient surface and the vascular plexus intersecting each other ; either partly within, at, and without the other ; the sentients receiving the images of the vessels and that of the foramen by reflection.

50. In considering if there be any circumstances which tend to eliminate any of these rival claims, it occurs that if the shadows of the vessels be disclosed after their reflection from any surface, the rays from the given pencil must not only pass the vessels, but must pass them *again*, and, consequently, whichever of the three positions the sentient surface hold, there must be, from the same pencil, a pair of shadows for each vessel,—if the sentient surface be the inmost, a direct one, and one with a parallax happening originally in the *again*-passing (reflected) rays. If the vessel and sentient points lie in the same surface, a direct one reflected with a decided parallax, and one happening originally in the *again*-passing rays, with no, or scarcely any, parallax. If the sentient points lie on the outside of the vessels, a direct one; and, with a greater parallax, the same direct one reflected.

In experimenting with the candle, I find that we may actually behold a notable supplementary version of the vascular figure. As we bear the candle round the eye, all over the more central parts of the visual field, though most clearly appearing between the optic axis and the flame, and gradually becoming more indistinguishable laterally, we may see, in a delicate guise, shadows of vessels as fragmentary black lines, of varying breadth and length (Fig. 50 may give, imperfectly, some notion of the appearance of these fragments), separated by lustrous interstices; conforming to the type of the vascular phantom when begotten by a bright line, as the back of a knife, moved across its length perpendicular to the optic axis, which only shows vessels and portions of vessels that happen to have a course parallel to itself. I observe, further, that the parallelism of the lines in the example before us for ever indicates the meridional (that through the optic axis) plane, which the flame occupies *for that instant;* in short, a changing illuminated picture, rotating about the optic axis, as the flame revolves round it; successively ushering in such vessels lying in the brightened regions of the retina as happen to be parallel to the said meridional plane, without developing more than a very slight parallax, *and that in the direction taken by the meridional plane.*

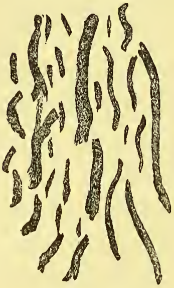

Fig. 50.

But not only the flame, but its retinal image keeps in the said plane; and that the phenomenon is dependent upon the latter, and not the former, is made evident from the fact that it makes its appearance in the experiment of viewing the vascular tree (47) by a focal point circulating upon the sclerotic. In the mode I have described, it seems to have escaped observation; but Helmholtz (Enc. d. Phys. S. 157) corroborates H. Müller in his account of the latter, and thus speaks of it:—"The spot itself has in H. Müller's, as in both my eyes, a peculiar aspect, which distinguishes it from the rest of the ground of the eye. The latter is uniformly lit up, with the exception of the dark figure of the vessels; the spot of the direct sight has a stronger lustre, and looks like shagreened leather. It is to be remarked, moreover, that when, during the observation of this spot, we fix the eye upon some external object, and now move the focus of the lens upon the sclerotic from below upwards, the vascular tree, as has been before stated, also moves upwards; the shagreened lustre on the contrary, glides a little in the contrary direction, downwards towards the fixation-point of the eye." He fancies that the phenomenon may arise from some recondite property of the punctum aureum, whilst Müller* says that it looks as if it arose from reflection, though he had not succeeded in detecting its origin.

Now in seeking for the solution of this phenomenon, I can detect that the shagreened appearance arises from illuminated capillaries, a fact that comparison with what is clearly the same manifestation upon a larger scale, as above characterized, makes plain. The next point to note is, that an additional quantity of light is found on the portion of the retina under consideration, and that when it is produced by the image of a flame, falling upon the inner side of the retina, and occupying thereon a larger surface, it presents a much larger area than when it proceeds from the external point of concentrated light. Again, as there is only one source of light, the excess of rays that fall upon the limited surface must be its reflected thereon (for there is no structure that can refract them thither). And the form of the wall of the posterior chamber of the eye is such that there is only one part of it adapted to reflecting light especially upon the back of the eye; that is, the part formed by the crystalline lens.

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* Verhandlungen der Phys. Med. Gesell. in Würzburg B. V. S. 422.

If we suppose the posterior, *convex* surface of this lens to reflect the light received by it from the image travelling over the retinal textures, the whole conduct of the phenomenon is readily comprehensible. Because the lens will form, by reflection, an elongated image of the retinal image in the plane that passes through the latter and its own axis, the reflected rays being thrown back, radiating on either side of this plane, on the side of the eye occupied by the retinal image. When this image is owing to light permeating the cornea in the ordinary way, it may fall more towards the back of the eye, and more directly over against the reflecting side of the lens; and, therefore, some of the light reflected by the lens, may extend further towards the image in one direction, and further, too, across the foramen centrale, than when it is owing to light concentrated externally upon the sclerotic. Should the image in either mode circulate in a plane perpendicular to the optic axis, the reflected light in question will always go round with the meridional plane, whilst the shadows of the vessels, which lie in that plane, at starting, retreat along the retina as the image advances. It is when the focus moves upwards within or without the cornea that the opposite movements of the vessels and shagreened spot may be witnessed; and that the latter actually mounting with the light appears to drop across the point of direct vision.

A look at the form of the posterior face of the crystalline as shown in the frontispiece or Fig. 1, will lead us to perceive why the shagreened spot shows itself near the central hole of the retina. For the external focus cannot move backwards in a meridional plane, except to a small extent; and rays radiating from a point near the ora serrata, by the law of the angle of incidence being equal to that of reflection, with such a flattened inclined surface as the crystalline presents, will, plainly, be reflected to the region of the punctum aureum. Also the same figure will render it obvious, that if the external focus move, in the plane mentioned, *from* the cornea, it will not be able to move far enough for its rays to fall at such difference of inclination upon the lenticular surface as to cause a notable movement of the shagreened spot in that plane.

The principal conclusion affecting the investigation more immediately in hand to be marked here is, that whilst an explanation is not wanting which satisfies all the conditions of the phenomenon of this fragmentary apparition of the vessels and capillaries, its deportment is at variance with any notion of a supplementary shadow of the order discussed awhile ago.

51. But besides this, we have yet another additional manifestation of the vessels. All the time that the flame is being whisked about the eye, each vessel, in a flickering, though in a forcible mien, keeps its own image, as

it were, stamped upon the sentients nearest it—just where it falls retinally when we look against the sky with the naked eye. If the flame has been waved about before one eye for a little while, and we close this organ also, a brilliant, glancing, exquisitely complete copy of the vessels will vibrate before us for a few moments; even if the protected eye be suffered to view a surface too faintly illuminated to impart strong images of the vessels to that eye, or to extinguish acute impressions upon the nervous substance of the other, the said vessels will actively disport on that surface. In fine, this phenomenon, I infer, is due to the circumstance that those sentients which lie directly under the vessels are usually less exposed to lucid stimulation than others; and that when light is made to flow over the retina in a uniformly-diffused fashion, they are *comparatively* much less excited, or rather much less *exhausted.* For as the shadows are only displaced by rays that pass them transversely, a light (or rays radiating from its image) circulating over the retina will strike the sentients under the vessels much less than others. Thus what we see is a *differential spectral* state of the retina.*

Save these two, not a glimpse can I catch of extra vascular spectres. The former has no existence with the divergent pencils we began with (45). The latter accompanies experiments by all the pencils, and might (its peculiar aspect apart) be regarded as an example of the sort of supernumerary phantom we are in quest of, were the sentient surface spread immediately upon a whole plexus of vessels; so that it might be difficult to say, *hence only,* whether that expansion were the inmost or outmost of the spherical stratification. Yet when we balance the intrinsic consistency of the explanation adopted with retinal anatomy, and the fact that this is borne out by entoptical phenomena in placing the vessels at variou retinals depths, whereas no membrane, nor any continuous surface contiguous to them *all,* overlies them, there seems to be little or no reason for attaching weight to this phenomenon, if found standing alone in ambiguous significance, in a sense contrary to the concurrent import of those remaining, if they shall be discovered to have such concord. Lastly, the other case imagined, of two shadows from the same radiant, would give birth to two pictures of the vascular plexus, so competing in size that they would breach one another, which does not appear to happen.

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* Whether any portion of this phenomenon may arise from the pressure of the blood in the retinal vessels, will be considered in the next chapter. The answer cannot affect the main question before us.

Being led, then, *per viam exclusionis,* to regard the vascular phantom as an immediate projection upon the sentient points, the question remains whether, somehow, the image of the foramen may not be simply a shadow similarly projected. H. Müller's suggestion seems worthy of consideration, and is to the following effect:

52. We do not see in waving the candle round the eye a uniformly dark circular area, nor a complete circle at all, at any one instant, though we may elicit the whole circle in the course of one revolution of the flame round the optic axis. At any one moment we see (Fig. 51) a crescent, whose convexity looks to be towards the flame itself, and is really towards the flame's retinal image, this crescent approaching half-moon shape as the image advances towards the foramen

centrale, and having a parallax like the vessels have, though of less amount. It is, therefore, the image of the crest of the wall of the central pit of the retina. I find that with $\alpha = 40^\circ$, $\beta = 4^\circ$ for the crescent, when for the same value of α, the vessel crossing the foramen, which presents the most parallax, gives $\beta = 8^\circ$. From which it results that the brim of the pit is 0·0036, or $\frac{1}{277}$ of an inch, and the vessel 0·0738, or $\frac{1}{136}$ of an inch, from the sentient surface.

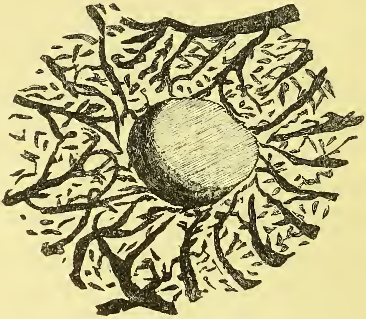

Fig. 51.

Strictly speaking, according to my apprehension, entoptics only enable us to determine that a slender opaque ring surrounds the point of direct vision, and that (in accordance with the calculation which I have supplied) it is situated at a certain distance from the sentient surface, but not so far in front of it as the retinal vessels, which most nearly approach it.

When the image of the flame, or radiant that projects the shadows, falls pretty far from the ring, I see no shadow of it—because, as I presume, it is too slender to cast a visible one. When it approaches it more nearly, a narrow shadow of the portion that lies nearest to it appears, whilst the opposite *transverse* portion shows none. When it has got near enough to yield a broad crescentic shadow of the nearest transverse portion, the further transverse portion (what other observers have seemingly overlooked) becomes discernible by a narrow shadow. This great difference in the shadows of the two portions depending upon the fact that the ring is so thin that the broad shadow is only produced when the radiant gets exceedingly near to any portion of it. Furthermore, it must be noted that the edge of the shadow in either instance, is armed with a reflective fringe, especially on that side that looks towards the radiant, just as happens with those of the opaque vessels.

Again, when the radiant is brought very near to the ring, the shadow manifests a parallax to more than twice its diameter, whence it must be thrown upon the sentient surface that lies without the region of the ring; and the ring must lie in a plane which passes in front of such surface. Hence there can be no foundation for the opinion expressed by Helmholtz, in reproducing Müller's views, that persons having the wall of the fovea not sufficiently steep might see no shadow, because the shadow is not merely thrown as he imagined, within the region of the fovea. Nor can the shadow be that of an opaque wall standing upon the sentient surface; for then it might extend from it, but could not be cast free from it.

In conjunction with these observations it may not be out of place to mention that if you oscillate the spread fingers, or even the side of the hand very rapidly before the eye, so as to expose the retinal expansion to a general rapid change of light, the portion immediately behind the vessels will render a sensation of whiteness, by which their ramifications can be seen. When, therefore, we remark that the portion behind the ring also distinctly presents us with the sensation of a white circle, the inference is obvious that the cause of this white circle is a material opaque ring.

Some anatomists describe the portion of the retina in question as consisting of a cylindrical lip projecting forwards beyond the level of the general retinal substance. Some say that the retina is simply deficient there in one or more of its layers, and that a pit exists. The difficulty in the microscopic investigation lies in the transparency of the portions surrounding the ring. But I repeat that entoptics demonstrate that there is an opaque ring, which lies in a surface of greater radius than that in which the vessels of the *punctum aureum* run, and in one of less radius than the sentient surface has.

From many entoptical trials, H. Müller estimates (infers ?) the interval between the "percipient layer" of the retina and the vessels situated at the circumference of the punctum aureum at 0·17; 0·19 to 0·21; 0·22, 0·25 to 0·29; 0·29 to 0·32 millimètres. In the case of three other observers, 0·19; 0·26; 0·36 millimètres: and these numbers harmonize very well with those I have obtained. Then, from anatomical measurements, he determines that the bacillar layer of the retina in the region of the yellow spot is from 0·2 to 0·3 millimètres behind the vessels, and from the elements of this layer pointing as normals to the retina and collateral reasons, he concludes that they are the percipients; that is, as I prefer to call them, the sentients (see Fig. 3).

At all events I cannot refrain from mentioning that, notwithstanding contrary testimony, I can scarcely persuade myself that I do not discern the completion of the capillary network in the region of the central hole, not only when I use a pencil of rays diverging in front of it, but when the shadows are cast by rays issuing from an external focal point on the sclerotic.

To all this it may be added, that in waving the candle about the eye the vessels wear a particularly wide border of reflective light on that side that appears towards the light; that is, on that side actually towards its retinal image, which this must illuminate. We can at once perceive that if the vessels are in front of the sentients this illumination must throw a reflective border where we find it; but, inasmuch as the rays that produce it must have a very different direction from those that continue in straight lines past the vessels from the image, they would not fall by the side of an image due to a second reflection. Thus the position of the luminous border confirms the conclusion that the vessels are in advance of the sentients. A similar remark may be made with respect to the opaque ring imagined to exist at the foramen centrale.

Chary as we may be in trusting to absolute calculations, from such observations as we can make, for the resolution of so principal a question as the primary seat of vision; yet it can hardly be gainsayed that a comparative scrutiny of all the phenomena fairly entitles us to decide that there is a certain anterior placing of the vessels and margin of the fovea with respect to the sentient surface, which appears to point with a high probability to the site assigned.

53. The light reflected from the interior of the concentric ocular tissues yields other accidental phenomena of vision. When we look towards a wall, near to which stands a lighted candle, not only do we not see the part covered by the flame, but a considerable circumjacent part is extinguished by the rays reflected from its image. Whenever the image falls in the foramen centrale, the lucid halo round the flame gradually diminishes (inversely as the square of the distance of any point in it from the flame) until it ceases to be discernible. If, on the contrary, it fall outside of it, the halo it carries, though it finally seems to extend until it gradually becomes too weak to be visible, at a certain distance from it abates so quickly as to show a tolerably defined loss of brightness. This quickly-dwindling halo wears a yellower hue than either the flame or the encircling fainter continuation of the halo. Or if, instead of a candle, we look obliquely at the moon, whose light is white, the halo in question will still be yellow.

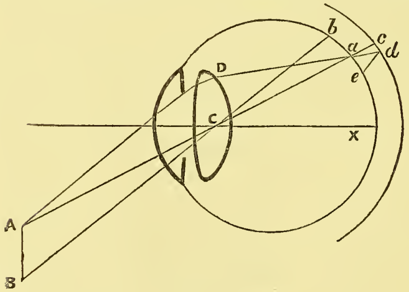

Fig. 52.

In Fig. 52, made disproportionate in some obvious respects, that it may not occupy too much room, we have sections of the eye through its optic axis X C, and of the moon through its diameter A B, the retinal image of which, since C is the optic centre, is *a b*. A D *a* is the extreme ray from A that the opposite margin of the iris suffers to pass from A to *a*. Let C *a* and D *a* be produced to meet some external tunic, concentric with the retina, in *c* and *d* respectively. From *d* draw *d e*, to meet the sentient surface, making the same angle with the tunic that *d a* makes. It is plain that *a e* must very nearly equal 2 *d c*.

Now if we suppose the greater portion of the reflected light to radiate from the sentient surface itself at *a*, to produce the general halo, but that a certain part reaches the outer tunic to be there reflected, were this smooth, the ray D *a* after reflection would cut the sentient surface in *e*, and *a e* would be the retinal width of the defined halo round the moon produced by such external reflection. The thickness of the bacillar layer, added to that of the choroid membrane, may average $\frac{1}{100}$ of an inch. Let the radius of the pupil in moonlight be $\frac{1}{10}$ of an inch. If C D were joined by a straight line we might regard the triangles C D *a*, *c d a* as similar; and, therefore,

$$\text{DC} : ca :: dc : ca$$

$$\text{or, } \frac{1}{10} : \frac{3}{5} :: dc : \frac{1}{100}$$

$$\text{that is, } dc = \frac{1}{600}, \text{ or } ae = \frac{1}{300}$$

Hence (6) *a e* subtends an angle in the field of view of about $\frac{1}{3}$ of a degree, which is, therefore, on the suppositions involved, the apparent breadth of the yellow halo round the moon; whose apparent diameter, being about $\frac{1}{2}$ of a degree, is thus somewhat greater.

It must be observed that the width of the halo thus obtained varies directly with that of the pupil and the distance between the sentient and external reflecting surfaces. And since, in many individuals, the pupil in moonlight is much broader than here assumed (probably, in some instances, as much as two-thirds) and the two surfaces may be further apart, the halo may be found proportionally broader. Even light may be reflected from the outer surface of the sclerotic as well as the inner, as we have been imagining, yielding a halo of a breadth of two or three degrees.

Upon the whole, I do not find the breadth of the yellow halo agree badly with the calculation I have instanced. It varies pretty much as I let the moon's image fall on different parts of the retina, and I am not supplied with accurate information enough about the changes in thickness of the choroid and bacillar layer to thoroughly test the hypothesis by such particulars. If the axis of the eye be directed a little above the moon, the halo looks very yellow and distinct, and pretty much so whenever the image falls near the central foramen. When thus observing it, if I pass the hand slowly across the pupil, I see the halo contract, showing that it is dependent upon the size of the pupil. And I think I do not deceive myself in believing that it especially disappears on that side of the moon that becomes first hid by the advancing hand (as we should cut off *e* in the figure by intercepting the ray A D), in conformity with this hypothesis.

It is when the image (3) falls on the *punctum aureum* that the yellowness is particularly striking; that is, where the cones alone constitute the bacillar layer of the retina; and if, when it falls beyond this region, there be still some yellowness discernible, it is not improbable that these portions of the retina may be yellow in proportion to the number of cones they contain; at any rate the colour of the yellow spot *gradually* fades away with greater distances from its centre. Where a reddish hue is mixed with the yellow, or the halo looks orange, this may arise from the blood in the vessels not being wholly invisible.

In a word, I conjecture that the yellowness of the halo may have a physical cause, that cause being the colour of the bacillar layer; or of the true sentients, the cones, which wholly or partially compose it.

On this view, the halo affords us the means of limiting, by calculation, the removal of the sentient surface from the sclerotic without, as the shadows of the vessels and brim of the pit do from these objects within. And even though it must be admitted that such nice calculations cannot be obtained from the halo as from the shadows, it is nevertheless of much interest in this point of view, as contributing another to the many facts which evince that the physical conditions of all the parts traversed by objective light are accompanied by corresponding spectres.

54. To complete our entoptical explorations, it remains to notice the well known phenomenon, discovered by Mariotte, of the insensibility of the base of the optic nerve to objective light, from which its point of entrance into the retinal surface has been called the punctum cæcum. If I look straight at the moon, and then rotate the eye directly from the nose until the axis has passed through an angle of 14°, it will quite disappear from the heavens, though it were visible before the axis had reached so far, and becomes so again when it gains a greater angle. This is because, at this number of degrees the moon's image is painted

on the base of the optic nerve, whose middle point (6) must therefore be $\frac{1}{7}$ of an inch from the foramen centrale. I find the image begin to disappear by the time it gets at $\frac{1}{10}$ of an inch from the foramen (3), and not to completely reappear until it has passed beyond full another $\frac{1}{10}$; showing the punctum cæcum to have a diameter of at least $\frac{1}{10}$th of an inch.

Or, though the diameter of the absolutely blind portion of the retina may not have quite this measurement, I am at any rate positive that when the moon's image occupies its middle, it is entirely invisible, though I have seen it asserted that bright lights in this region are not entirely extinguished from view. On this condition I do not see the moon; nor do I see a halo round it,—an instructive fact, as instancing that where the rays that paint the image find no external coat of the eye accessible, the partial halo whose origin we have been speculating upon is not observable.

55. The shadows of the vessels of the retina are not only brought into view by the methods investigated, but present themselves to us under more ordinary circumstances. Thus, if we swiftly sweep the axes of the eyes over the sky, the shadows of the vessels and, in some degree, of the foramen centrale show themselves for the instant. If we walk along by a hedgerow, or a row of railings, through which the sun shines, the *vertical* branches of the vessels, as the eye is fitfully exposed to and shaded from its rays, pop and flit in our path. Every time we open the closed eye we may catch glimpses of the vessels. But if the eye has been kept from light for some time, an image of the vessels may, on opening it towards the sky, be discerned which is not

altogether shadowy, being white, and attributable to a differential condition of the retina in respect to the parts that are under the vessels, and the remainder. If we wear pin-holes before the eyes like a pair of spectacles is worn, on every movement of the head such vessels as lie transverse to it intrude, by their shadows, upon the field of view; a fact that should be remembered by those who recommend patients with conical corneæ to wear pin-holes before their eyes. If we hold a straight object by the side of the eye, so as to narrow the pupil, the very fact of reducing it to a slit causes the vessels that are parallel to it to come into view on a movement of the head in the perpendicular direction; and if the object held there be such as to reflect light more or less freely from its surface, there is another source from which the same phenomenon may arise. I have seen it proposed to remedy astigmatism by cutting off the weaker of the two images, by thus narrowing the pupil. It is well to bear in mind this incidental consequence of such a contrivance. The frequent spectral manifestations of the vessels would prove a very great annoyance. Moreover, incessant transitions from light to darkness, or from less to more light, and *vice versâ* prove very aggravating to the eye, even painfully exciting its nerves and parts associated with it, and unduly stimulating the secretion of tears and mucus.

Hence all flickering lights are bad for the eyes. If the sun shines through a blind of any kind of woven material into a room, it irritates them to read by the light supplied; for their necessary movements suffice, under such conditions, to *tickle* the retina with the rays of light impinging upon it from detached points. For whether the light reach the eye directly from the blind, or after reflection from the book, it will, so to speak, strike the retina from *mosaic* sources. In addition to which, I suspect that there may be a difference in the quality or kind of light when some of the rays enter through minute holes, and some penetrate the fibres of which the blind is woven, and that transitions from one sort (colour for instance) of light to another may torment the retina.

There are certain globes of glass so ground, or rendered partially opaque by some process, used for lamps, (when the flame, though steadier than that from a jet of gas, being never quite still, is an additional means of mischief) where the inconvenience just described is felt to be intolerable. In such a case as this, provided the fault may not lie in an oscillating flame, if we remove the globe, and avoid looking at the light, the eyes recover their composure; and just so, in the previous example, we have only to let the sun blaze into the room unrestrained, provided its rays do not fall directly on the book, or subdue the light by partially closing the window-shutters instead of by the blind, and our eyes are relieved.

56. In his history of retinal entoptics, Helmholtz (Encyk. d. Physik, S. 163) tells us that Purkinje was the first to observe the shadows of the central vessels; that he saw them with a pin-hole in motion before the eye; by light concentrated by a lens, travelling over the external surface of the sclerotic; and by the lateral movements of a candle. But that he did not observe their parallax. It was Gudden, he continues, who supplied this observation in 1849.

* Beiträge zur Kenntniss des Sehens, 1819, S. 89. Neue Beiträge, 1825, S. 115, 117.

Since, however, Wheatstone,* whose name he does not notice in connection with this study, had long before described the parallax, and maintained that the vessels were in front of the sentient surface and seen by true shadows, I must interpolate a notice of his views. I have not read the first account he gave in the journal referred to below; but write with an abstract before me of the one he uttered the year after, in the presence of the British Association. In the Report, his remarks occupy hardly more than a page, but contain sufficient details to show that he discovered and studied the parallaxes; whilst it puts in italics the nervous law of vision assigned to him awhile ago (45). This law, as we shall have occasion to note in the next chapter, in being an unobjectionable statement of a fact, leaves some curious accompaniments of the nervous phenomena unexplained.

The abstract affirms that there is a visible central spot in the retina when a candle is moved to and fro, laterally to the eye, but does not directly speak of its having a parallax. Its only other defect is that it does not take care to state that the shadows issue from the retinal image, and not immediately from the flame, when their opposite movements to the latter are mentioned as a proof of parallax.

Among some manuscript extracts from the journal which I have perused, one shows that Wheatstone diligently studied the parallax of the central shadow. Among other expedients he adopted for this purpose, was that of watching its movements about the spectrum of a coloured wafer impressed upon the retinal middle. He notes its crescentic shape, and ascribes it to a projection from the retina. But neither in this nor in several other extracts having reference to the shadows of the vessels, can I catch a word which implies that he regarded the shadows as pertaining to the retinal image of the light, though I should have imagined that had he conceived such a thought, it would have been *paraded* in almost every sentence.

According to H. Müller, it was Meissner who first maintained that the shadows moved as if projected by some other source of light than the flame; not to point out what source however, but as one of his objections to their being considered as shadows at all.

Helmholtz speaks of Burow as having diligently investigated the manifestations of the central shadow, who regarded it as proceeding from a cone standing upon the sentient surface. Meissner has also written much on all the shadows, but he denied from most unsubstantial principles that they were shadows at all. It seems to me that no one contributed after Wheatstone any materials serving to elucidate this object until H. Müller produced the essay* already referred to.

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* Journal of the Royal Institution of Great Britain, vol. i. pp. 111 and 534, 1831. Report of the British Association, p. 551, 1832.

Since this writer has been among the most successful investigators of the microscopic structure of the retina, we have the benefit of seeing his measurements obtained in this way by the side of those obtained by him entoptically. In fact we could do nothing definite in the latter way without such measurements as he has supplied us with of the thicknesses of the different retinal layers. It may not be amiss to mention, however, that he expresses his regret that the difficulties in the way of such researches render him unable to assign more reliable dimensions, and that those he gives us are only the *means* of several, where instances are met with deviating considerably from these. The measurements he makes of the thicknesses of the different retinal layers were confined to the limits of the yellow spot; so that there is much desirable information of a kindred sort for future investigators to supply. I may say that the scheme of his essay bears a general resemblance to that of this chapter, and that Helmholtz makes it ("as the completest theory of these phenomena") the foundation of the corresponding portion of his article on Entoptics. Nevertheless, scarcely in any instance have I trodden in his footsteps, whilst I have turned aside into regions which he left unexplored.

He claims (and Helmholtz concurs in his claims) to have been the first to discover that the shadows of the vessels in waving a candle near the eye are projected from the retinal image; and (as far as I know rightly) to have been the first to conceive the idea of calculating the distances of the vessels from the sentients by means of the parallaxes of their shadows. To accomplish this end, he selected the experiment in which light is concentrated by a lens on the outside of the sclerotic, and observed the shadow of a vessel on the confines of the yellow spot for two positions of the focus; one of the positions chosen being at or near the circumference of the cornea, and the other in the same meridional plane at or near the equator of the eyeball. If in Fig. 48, A′ had been placed on the same side of the optic axis as A, and near the (bottom) margin of the cornea, A′ and A would have represented the two sites of the focus; and E being the vessel, by joining A′ A by a straight line and B′ B by another, we should have a geometrical construction such as he gives. It will facilitate description if we speak with reference to this figure, thus modified in the imagination.

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* Ueber die entoptische Wahrnehmung der Netzhautgefässe, insbesondere als Beweismittel für die Lichtperception durch die nach hinten gelegenen Netzhautelemente. Von H. Müller. (Vorgetragen in den Sitzungen, vom. 27 Mai und 4 November, 1854). Verhand. d. Phys. Med. Ges. in Würzburg. B.V. S S 411—47. 1855.

An assistant measures on his sclerotic with a compass, the chord A′ A, which he assumes to be retinal. He calculates in the usual way from the parallax of the shadow the length of the arc B′ B, and assumes this to be the length of the chord B′ B. Then from the two similar triangles A′ E A, and B′ E B, he gets

$$\mathrm{B\,E} = \frac{\mathrm{B'\,B}}{\mathrm{A'\,A}}\,\mathrm{A'\,E}, \text{ and } \mathrm{B'\,E} = \frac{\mathrm{B'\,B}}{\mathrm{A'\,A}}\,.\,\mathrm{A\,E}$$

Then if the lengths A′ E and A E be known, the oblique distances B E and B′ E of the shadow-throwing vessel from the sentient layer may be determined.

Now suppose F E C to be produced to meet the circumference of the eye in G (a point that falls on the other side of the cornea in his figure) so as to become a diameter of its section, then from a well-known property of two intersecting chords, he gets

$$\mathrm{F\,E} = \frac{\mathrm{A'\,E}\,.\,\mathrm{B'\,E}}{\mathrm{G\,E}}$$

from which F E, the perpendicular distance of the vessel from the sentient surface, may be obtained. Such are the three equations which he employs in the entoptical investigation.

However, in order to use them, he must, he finds, somehow determine the lengths of the lines A′ E and A E (the length of one might have sufficed). But instead of proceeding to do this from entoptical observations, he measures in a number of dead eyes with the compass the distance of the yellow spot of the retina from the sites he selects on the sclerotic for the foci to rest at, or (which may be made to answer the same purpose) from the margin of the cornea. From the *means* of the measurements he assigns the two lengths in question. He then selects for observation a vascular twig, which approaches the confines of his foramen centrale from *above or below*, that it may lie transversely to the rays of light issuing from the radiant on the sclerotic; for in using the term, yellow spot, he considers it, as it would seem, only to apply to the immediate vicinity of the central hole; and can have no better guide than the point of direct sight by which he can assure himself that the vessel has a position which accords with the measurements he employs.

Hence Müller only makes his method of calculation available for vessels in the punctum aureum, and devises no way of finding entoptically the site of such a vessel.

Helmholtz, in adducing this project of Müller's for calculating entoptically the interval between a vessel and the sentient surface, omits all mention of his anatomical mode of assigning the distance of the vessel from the focus on the sclerotic. Preliminarily to a statement of Müller's numerical results (52), he furnishes a diagram modified from his, which merely indicates the apparent parallax of the vessel produced by the movements of the focus on the sclerotic; and adjoins that its "distance from the retina may be found by measurement or calculation."

In a word, he could not have failed to be conscious that a resort to *measurements* upon the dead eye, for getting at the last terms of Müller's two equations, deprived his conception of all claims of being accepted as an entoptical *method of calculation*, even for the special case of a vessel lying in the punctum aureum. It is palpable that Müller was at a loss to solve the general entoptical problem of finding the distance of any retinal vessel from the sentient surface; whilst Helmholtz contents himself with hinting the possibility of its solution for vessels "in the neighbourhood of the yellow spot."

The calculation of the diameter of the foramen centrale had been made by many preceding observers, and, I have no doubt, the place of the base of the optic nerve had often been found entoptically, just as I have found it.

Müller shows how there would be a pair of shadows of a vessel if shadows were seen by sentients lying within it, after having been reflected from a surface lying without it. He mentions the reflective margins of the vessels, but draws no argument from these as to the place of the sentients. Neither he nor any other author I have consulted has, as far as I remember, observed that it is only the pulsating vessels that appear to us in daylight with the *still* naked eye, though I deem it not unlikely that some writer may have noted this fact.

Excepting phenomena dependent upon the nervous properties of the retina, of which I shall speak in the next chapter, I have cited, to the best of my information, all such observations and calculations on the subject-matter of this chapter made by my predecessors, as are worth particularizing.

CHAPTER VII.

APPENDIX.

Visual Sentients.

57. Having expended our means of analysis by aid of entoptical parallax, and allied helps, when we arrive at the seat of the sentients themselves, we must resort to other expedients in order to get some acquaintance with their differential structure, as affecting the

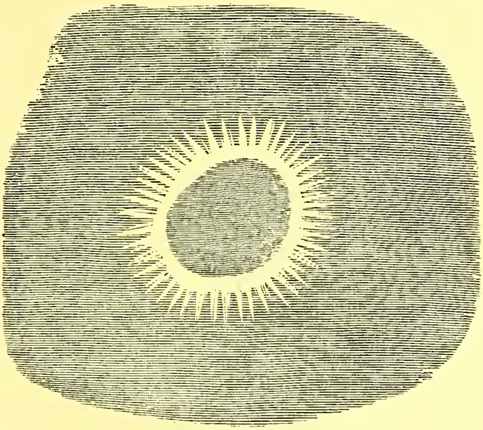

Fig. 53.

The middle grey spot being the image of the finger-tip, the white ring shows its contour, though, perhaps, the image is too abruptly marked, and the ring too much fringed with rays.

use of sight, and with any troubles of vision that may arise from the working of the machinery of the eyeball. Such knowledge is requisite to protect us against any error that might else creep into entoptical research proper, from a posterior source; also it may lead us directly to a more fundamental idea of the mode in which light stimulates the sentients. I shall proceed as systematically as I can under the altered circumstances.

If the extremity of the finger (Fig. 53) or nail be laid upon the sclerotic immediately, or through the lid, *even never so lightly*, in the nearest attainable regions to the most sensible parts of the retina, we shall elicit a quasi-luminous areola of the contour of the applied surface, though the surface itself seems lit up but in a very meagre degree, or not at all—that is, unless the applied surface be very small, when the brightness of the areola will so encroach upon the included area as to make it difficult to say whether it pales away entirely at the surface itself or not. Thus the resulting image of the surface simulates the shadows of opaque bodies embedded in the retina, with their reflective borders. This marginal effect must, as Young remarks,* be due to the flexure undergone by the retina along that line. He says *greater* flexure along the contour than upon the applied surface; but I would wish to make the distinction that, though it is obvious that such a flexure as crowds together the internal elements of the retina produces a sensation of light, yet the experiment seems to yield no evidence that the bare pressure upon its outer surface, or the sundering of its elements from one another in the act of depression, has any consequence of a similar kind. Hence, we might infer that it is only the inner surface of the sentient layer which is sensible, or if the cones rather than the rods are sentients, that the rays of light affect them by impinging upon *their sides.* And if this be the arrangement, that each little sentient surface should be veiled from pressure in a little pit, we might perceive why the most employed portion of the sentient expansion should be walled in at the bottom of an abrupt fovea.

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* Philosophical Transactions. 1793.

58. When we turn in the dark the eyeballs sharply, or even mildly, a couple of white circular rings, brighter at one margin than the other, each enclosing a paler area with a central dark spot, flash forth, the diameter subtending an angle of several degrees. They are angularly apart from each other, and from the spectrum of a bright disc planted at the foramen centrale, and enjoy lateral angular play in strict conformity with the received opinion that they originate at the base of the optic nerve. The phenomenon is plainly the result of flexure of the retina where the nerve runs into it, as the eye is pulled round in its socket until it drags upon the nerve. And it is to be noted that it is *again* where the inner retinal elements are squeezed laterally that the phenomenon is disclosed.

If we turn the closed eyes in daylight in the same quick manner, we observe that a pale bluish light fills up the image of the base of the optic nerve. But we observe too, that when we regard a broad white surface we are not conscious that the base of the nerve is blind, and, hence, infer that impressions made upon the circumjacent portions of the retina must be projected into the field of vision, so as to fill up the angle occupied by the base. In the same way we must conclude that the blue light opposite the base is not owing to any stimulation of it, but is projected by the *creased* portion of the retina at its border.

59. If we compress the eye with the hand, through a soft cushion applied upon the closed eyelids, it is plain that the contours of all the harder more projecting structures of the orbit, which lie behind the eyeball, will have a share in the consequent false sensations of light; whilst the flattening of the globe between the cushion and the orbital structures must occasion false sensations at and near the eye's equator. Also, if any structure lying within the sentient surface were unyielding enough to cause the retina, when the globe is flattened by pressure, to bend over it, there would appear a lucid image of its applied surface; not a dark one with lucid margins, as in the case of a surface applied on the outside of the retina.

Thus, it might not seem impossible that the central vessels of the retina, though they do not touch the sentients, might be made apparent by direct pressure on the globe. H. Müller, and, I believe, Purkinje and others have fancied that they can thus get glimpses of some portions of them, though, as far as I know, they do not explain the precise way in which the phenomenon happens. However, the lucid lines and figures that arise on compression of the globe, unless I deceive myself, do not enable us to recognize in or among them, any portion of the central vessels, and it is very improbable that the central vessels could impress their images in this way. It is much more likely that the choroidal vessels supported by the sclerotic coat should do this. By direct compression, the creases formed in the globe, and the contours of the external resisting objects produce so many lucid spots and tracings that there is, it is to be presumed, no room for the apparitions of the central vessels to evince their pressure.

Besides, when a great force is employed in compressing the eye, the fluids within, distributing its effects equally in all directions, may be the medium through which the elements of the bacillar layer are so squeezed in a radial direction as to suffer excitement; or if these are compressible, they may be made to expand in the transverse direction until they press against one another, and a sensation as of light be engendered.

The most characteristic colour of phenomena from pressure may be white; whilst there may be some tendency towards the less refrangible colours. But the more refrangible are also often witnessed. Indeed, if the globe be severely pressed upon, all sorts of lucid vibrations are produced; doubtless, the particular one which is anywhere manifested, being dependent upon the amount of pressure which happens to be experienced. If the force used be slight, we only observe transitory lucidities; but if it be great and prolonged, the eye retains the impressions in the condition of *spectra*, which undergo the same changes of colour as those produced by the action of light, and may be equally enduring with the latter.

It is well known, that by a strong contraction of the orbicular muscle, as in yawning, the globe may be so compressed as to occasion lucidities like those just described. But can the orbital muscles, unaided by the orbicular, produce any similar effects? that is, can any like effects happen in this way in the open eye?

60. There are six muscles attached to the sclerotic coat, four before, and two behind the equator of the globe. These orbital muscles aided with fatty and connective tissue form a soft bed for the globe, and whilst, as is usual, their actions are concordant and supplementary, they keep it, as it were, *suspended;* so that the eye is wheeled round smoothly, with no sensible resistance to the traction of the muscles; and with no liability to have its sphericity disturbed. But should either one of the muscles contract very strongly, whilst the others remain relaxed, that would tend to drag outwards its inserent portion of the sclerotic; and thus to cause the underlying portion of the choroid followed by the retina to bulge out,—that is, to squeeze the sentients laterally in such a way as to produce a sensation of light. Again, by pulling the eyeball against its own knotted substance, or the harder of other objects in the orbit, it may depress it, and cause a retinal sensation, along the margin of the depression. The four straight muscles in simultaneous contraction tend to flatten the globe behind, and to expand it unequally at its equatorial region, and thus to excite the retina in parts; that is, wherever its curvature is increased. The two oblique muscles, when in unusual contraction, tend to drag out the portion of the retina lying under their aponeurotic insertions; which are situated so far back on the ball (above, below, and on the outside), as to correspond to very sensible parts of the retina, where it is readily stimulated by flexure.

After the experience we have gained of the instantaneous respondence of the visual sentients to very slight touches of the sclerotic, and to a gentle pull at the optic nerve, we should anticipate that these muscles are powerful enough when acting irregularly to produce marked retinal sensations; and that even some lucid effect may be discerned, when one or more of them act with no unusual energy. Indeed, as I believe, certain waves of light due to this cause may frequently be detected passing over portions of the visual field.

But it is when the muscles are provoked into a state of spasm that the most decisive results of the kind ensue. If by force of will we stubbornly constrain an eye to stare long in one direction, the muscles will finally become excited to involuntary contraction, and will pull in vehement antagonism to one another. Then dragging spasmodically at the globe, both before and behind the equator, in spite of the quantity of soft fat which they embrace, these muscles squeeze it against their knotted bellies and other orbital protuberances, loosening their hold and clonically enforcing it again; not only striving to drag the coats outwards at their insertions, but variously flexing the retina.

If we gaze against the sky or any illuminated surface, or, what is convenient for the experiment, the ceiling of a room in twilight, when the muscles are being thrown into spasm, we may see waves of (very frequently yellowish) light intrude upon the visual field, or gush over it. But the criterion of the amount of lucidity to be engendered in this way should be, apparently, to perform the experiment in the dark. I have, several times, attempted to do this, but to my surprise have failed to beget a thorough spasm of even one of the orbital muscles in the dark, though I can quickly do so in daylight. If I fix the eye resolutely in any one direction when I can see nothing in the distance upon which to direct the attention, after a short while I let the muscles, unawares, suddenly relax themselves in spite of my desire to keep them on strain. Thus I am only able to obtain faint lucidities in this way in a dark room.

One cannot be deceived as to whether the ocular muscles have been cramped or not, owing to the pain engendered, and left behind by the event. For after they have been thus tortured, the ocular tunics, especially where the muscles are attached, have been rendered painful; and the motor muscles of the globe, or some of them, excessively fatigued and sore; nay, in an appreciable degree, perhaps, not only also the orbicular and levator palpebræ muscles, but even those within the globe, the iridescent and ciliary, may have suffered. This soreness may afflict us for hours, and even days: insomuch that I shrink from frequent repetitions of the experiment.

61. Such unwonted efforts of the orbital muscles entail collateral effects. As we strain the eye with a divergent or convergent pencil in use, we see that the iris, at the moment that the orbital muscles most violently pull upon the ball, contracts greatly. It may be because the retina is practically, as to objective light, darkened; but more probably from consentaneous muscular action. I have nobody at hand conversant with the laws of optics to watch the conduct of the images of a flame from reflections at the cornea, and two surfaces of the crystalline lens when I strain my eye. But I

have no doubt that one or more of them would exhibit some instructive variations in aspect. An intelligent observer, whom I had not previously told what sort of changes to look for, was struck with the dilatation of the pupil, and so particularly with the behaviour of the posterior inverted image, that he always forgot to notice the others. At the instant of spasmodic strain, as the pupil enlarged, the inverted image, as he expressed it, "dilated and retreated from his view, even quite from his view;" as if the lens became flattened behind by a radial contraction of the ciliary muscle, similar to that displayed by the iris.

62. I am not aware that any author has called attention to the influence of the orbital muscles in the production of false sensations of light. But there is a phenomenon that very commonly shows itself mixed up with such sensations, but which may, I am persuaded, occur independently of them. It has been studied by Steinbuch, Purkinje, Ruete, and many others. They have regarded it as due to the pressure of the blood in the central vessels upon the retinal substance. It may be seen by looking steadily at the sky, or a large sheet of white paper, as they recommend. I find, too, that if one eye be closed, and the other kept continually moving about, or if the lids be quickly shut, and opened without stop for about a minute, a like effect will ensue. It will be found to be a very good plan to use a convex lens of large aperture, and condense the light from a candle to a focus in the pupillary opening. We thus expose the whole retina to a diffused light of *uniform* intensity, and obviate the risk of impressing *spectra* of different characters upon it, whose presence would

be a hinderment to our having an opportunity of studying the phenomenon in question in an uncomplicated aspect. When I expose a retina to such light it almost immediately begins to present to my view an appearance of effervescing points; and, after awhile, a furious whirl and seething of brilliant and grey patches, which is truly astonishing to behold. These brilliant and grey patches are perpetually dilating and contracting, yet I deem it certain that their shapes are in the main determined by the mapping out of the retina, by the ramifications of the veins and arteries that run through it. Indeed, whilst a sort of grey region seems to run along by the larger vessels, there may be witnessed, at least in many instances, a sort of brilliant punctiform current in the line they take, which Meissner, according to H. Müller, compares to the circulation in the web of the frog's foot, as seen under the microscope. The latter author does not see this punctiform current. I see it readily; but I observe that if I suddenly cover the eye when the phenomena now described are in full play, I see for full a half of a minute the tracks of the principal vessels mapped out by shining white lines, without any semblance of points hurrying along in given paths, though these lines, I suspect from incessant variations in their breadths, give me the idea of an intervention of active currents of fluid.

However, we must not forget that the vascular map, drawn in white lines, is always extant *in the condition of* the retina. When resting still in bed, in a dark room, we may discern it; only in this case the presence of one for either retina in the field of vision prevents either set of ramifications from being traced. Even in the middle region (that area which in both retinæ should be represented by the foramen centrale) of the conjoint visual field, I can see at night, unless I strongly deceive myself, distinct capillary meshes, just as dots can be seen in this region by day on the vibration of a pinhole before the eye. When the two intersecting vascular figures are seen in this way at night, they rather consist of steady than tremulous lines.

Now we may imagine, as some have done, that those sentients which lie directly without the branches of the vessels, being habitually less exposed to the stimulus of light than the intermediate ones, may be constantly in a state which deviates from theirs. Thus, if the whole retinal expansion remains, when not exposed to light during a whole night, more or less in a state of excitement, that portion under the vessels being the less exhausted manifests itself in a white guise. In the same way, we may imagine that after the retina has been recently exposed to an extraordinary amount of illumination, the sentients protected by the vessels may, for awhile after its cessation, manifest themselves very strikingly in the same way. That is, in either case the phenomenon arises from a sort of spectral condition of the whole retinal area. This, to my apprehension, is the true explanation of all the white manifestations of the vascular trees.

The vessels for the most part are placed at such decided distances from the sentient surface, that it seems inconceivable that they can impress their figures upon it by mechanical impulse. H. Müller seeks to obviate this objection by suggesting that the strata in which the vessels run, may be sensible to their impulse though not to that of objective light; he instances the cellular and fibrillose (see Fig. 3) layers as probably thus directly responsive. But it is plain that were the latter layer so acted on no *definite* figure of the exciting object could result. Besides, we know that when we get the image of the base of the optic nerve, by turning the eyes strongly in the orbit, the fibres of the optic nerve must be bent and compressed, yet no diffused sensation of light results. And when we depress the sclerotic the whole of the layers are flexed, and did any one of them as well as the bacillar yield an independent sensation, we should have, if not a double, bright areola, at all events, a very broad one, as the image of the outline of the depressing surface.

Nevertheless, though the bright figure of the vessels be attributable to a *spectral* differential condition of the retina, it does not follow that none of the accompanying phenomena originate in a disturbance of the circulation of the blood. The eyes rotate fitfully, all day long perhaps, as well to facilitate the free flow of the blood through the arterial and venous trunks enclosed in the optic nerve, as, with the aid of winking of the lids, for the equable distribution and removal of the fluids on their surface. When we fix the eyes, that is, check their lifting with the arterial impulse, or making their customary fitful movements, we, for a time, observe the retinal arteries, through their shadows armed with reflective fringes, as if gaily dancing in the visual field; and thence know that the retinal circulation continues: finally, we cease to see these movements, but not before objects in the external field of view begin to wane, so that we cannot infer from this that the current of blood has been checked. With the help of an experienced ophthalmoscopic observer who might note whether any change in the activity of my retinal circulation is apparent to him, when I am conscious of the occurrence of the phenomena now under consideration, I dare say that this interesting point might be determined. Many cases of fitful retinal circulation being observed with the ophthalmoscope are reported; but these have not been connected with any coincident visual experience in the patient. In the absence of such a coadjutor I am disposed to conclude that the phenomenon is owing somehow to compression of the optic nerve, so as to hinder the transmission either of the blood or of the nervous impulse. Even when the eye gets affected in the manner in question, whilst it is purposely kept in incessant movement, this sort of hinderment may accrue, by the dragging-about of the nerve and muscular pressure on its sides. The experiment always bequeaths a greater or less feeling of weight and tenseness at the back of the orbit; but I believe a good part of this is due to fatigue of the straight muscles, and that it does not indicate a congestion of those parts.

I doubt if any degree of the phenomenon can be produced in the dark, and therefore it is not attributable to the irritation of the retina, by an unusual flow of blood stimulating its sentients by its proximity and force. The essential feature is, according to my judgment, a blunting of the retinal sensibility, and that in a patchy or unequable style.

A long suite of illusions originate from the presence of the phenomenon. For every surface before the face whose image encounters it is sullied or expunged. If the eye rests gently upon some point of the wall of the room, patches of the pattern of the paper, the strings by which the pictures are suspended, or whole pictures, are buried in a mist, or entirely extinguished, singly or in groups, from moment to moment. And even if the other eye be brought to the rescue, but partial relief is obtained, for both retinæ are very commonly affected at correspondent regions. In combining two pictures into a solid form by the stereoscope much of this obliteration may obtrude itself.

If we lay a task upon the orbital muscles, as by regarding intently some object placed so near between the two eyes, as to demand an unusual contraction of the internal straight and superior oblique muscles; or if with absorbing effort we gaze towards the hands of another person so waved about before our face that the distressed eyes rather fixedly stare forwards than succeed in following their motions, the above events crowd upon one another, or even absolutely overwhelm the visual faculty. If a landscape is before us, when we strain our eye, and even, with some qualification, both our eyes, as the muscles are thrown into paroxysms of spasm, trees, houses, and fields take their departure here and there, through considerable angles; yet the degree of brightness of the objects tells upon the result —a moon certainly may be quite put out of sight, a sheet of water illuminated by the sun possibly, but the sun itself, in my experience, can never be thus removed. In a room the same phenomena prevail—pens, paper, &c., strewed over the table, flit away as if by enchantment; and even the flame of a candle may be thus extinguished.

That the phenomenon here described occurs in those persons who become affected by what has been called the Mesmeric influence, I have no manner of doubt, nor that it is the starting-point of their experience, as well as of those who feel affected by the proceeding of forcibly bending the eyes together as substituted by Mr. Braid. In some persons the brain itself may become affected secondarily to the eye (if not by obstruction in the small ophthalmic artery casting an additional pressure upon its arteries) by the transmission of irritation to the vessels by the medium of the sympathetic nerve and the consequent modification of its supply of blood; or there may be some reflex action upon the brain itself from the optic nerve. However this may be, I have been obliged to abandon an ophthalmoscopic examination because the patient fell into a Mesmeric sleep or coma, an event that happened with her on a second trial.

63. I ought not to neglect to record that there are certain transient lucid waves, chiefly of orange, yellow, or white light, observable in the field of vision on awaking from sleep. They make their appearance very distinctly, either in the shut eyes, or against a feebly illuminated white surface; they invade any portion of the field of vision. They often show themselves very brightly with irregular outline, though with a roundish tendency, just in the middle corresponding to the most sensible portion of the retina. Again, they spread from some lateral centre, and attain various shapes and sizes before they vanish, which they always do quickly.

Now, after sleep the recreated sentients respond to a gentle stimulus, and the twelve muscles attached to the sclerotics of the two eyes have insertions thereunto opposed to almost every part of the visual vault; insomuch that if it be that these lucidities are produced by the jerking of the orbital muscles upon the sclerotic, they are likely to show themselves wherever the sight ranges. I have sometimes almost persuaded myself that I could detect that the lucidities make their appearance opposite to the insertions of muscles that I feel to contract *involuntarily;* but the number of the muscles is too great to enable me to satisfy my mind upon the point.

Indeed, I have sometimes fancied that the phenomenon, which, I repeat, is a striking one to whoever may have learned to detect it, originates behind the retina, and has some parallel to the irregular fitful style in which the brain recovers its intelligence after sleep; whether both be due to a change in the circulation of blood through the central nervous mass or any other common change. But a presumption against this view is to be found in the fact that none of the other special nerves contribute sensations on such occasions. Again, we have, it may be recollected, strong evidence that it is very difficult to excite a sensation of light by direct stimulation of the optic nerves (57 and 58), whilst we have no *proof* that it is thus capable of yielding a sensation at all. The optic nerve may be, however, like the nerves of common sensation, only very much easier to excite at its terminal points than in its course.

64. Having now discussed all the different ways in which the sight may be interfered with by mechanical action upon the retina, I must allude to certain phenomena arising from the differential structure in different parts of the sentient surface, which, if not

noted and eliminated, are likely to deceive us as to the extent of some of the phenomena which have been considered in this and the foregoing chapter.

Though I have been in the habit of speaking of the region of the foramen centrale as the most sensible part of the whole retinal expansion, and though we only use this part in our current avocations in obtaining definite views of the objects we look at, yet, as has been remarked by many observers, it is in reality less sensitive to a weak light than the rest of the retina. Small stars that are not discernible with direct vision are clearly so with oblique. There is a time in the evening, as night is coming on, when fragments of white paper lying on a dark table appear to view every time we turn the eyes within the limits of the visual field away from them, though quite invisible when we look at them.

Just before the twilight has become so faint as to produce this effect, a degree of light exists in which another notable phenomenon presents itself. As we wink the eyes, every separation of the lids is attended with a momentary phantom of the central hole of the retina, that wears the aspect of a shadow of it. But it must be observed that when this is elicited there is not light enough for the shadows of the retinal vessels to show themselves.

Now it is an established fact in experience that luminous impressions made at the foramen are more lasting than those made without its confines. It seems to me, then, that in order to explain the observations just recorded, we must assume that it requires a greater momentum of objective light to make them at the middle of the retina; or, that when the light is faint, but still strong enough to stimulate it, it takes it an instant longer to affect it than it takes it to affect the circumjacent regions. Hence the central shadowy appearance we see in the sort of light described is not, in the main, the shadow of the opaque ring that limits the so-called fovea.

65. I will here fulfil my promise of returning to the consideration of the question of the invisibility of the shadows of the retinal vessels, except when they are continually changing their places on the retina. The question is a difficult one to answer satisfactorily, and I cannot say that I have anywhere seen it so answered; or that I do not shrink from saying that I feel myself competent to do so. Wheatstone, who first observed the fact (we are told in the Report of the British Association, 1832), "adduced several facts which tended to prove *that an object, either more or less luminous than the ground on which it is placed, when continuously presented to the same point of the retina, becomes invisible.*" But supposing him not to have been misled by the phenomena described in 62, these facts do not explain those of like kind contributed by the shadow, but merely with them require an explanation. The real issue of the question is not met. If these shadows or these images simply *vanish* from the field of view, *nothing* appearing in their places, there would remain in the field *dark* images corresponding thereto. Helmholtz, after concluding his summary of H. Müller's and other studies of these shadows, attempts an explanation, which involves the same defect.

Now if a shadow with its bright reflective fringes ceases to leave marks of its presence in the field of view when the mind directs its attention to that part, it seems to me that an *irradiation* of *sensation* or else of *perception* must have occurred.

If the additional illumination of the retina supplied by the reflective border should be able, in the course of a *short while,* to stimulate the shaded sentients by the propagation to them of some of the additional excitement of the adjacent ones, this might account for the disappearance of the shadow; but unless we suppose, at the same time, that the adjacent sentients lose some of their own excitement in this lateral propagation, we cannot account for the disappearance of the reflective borders.

In a word, if we confine our thoughts to the phenomena of these shadows, on assuming that there is a tendency in the retinal sentient elements which are in juxtaposition to mutually affect each other, but that a certain lapse of time must take place before they can accomplish this, the disappearance of the shadow with its reflective border from the field of view may be understood. Or if we assume, instead, that irradiation of sensation goes on *at a certain rate*, in the optic nerve, or brain itself, we shall have an equally available hypothesis.

If, in place of resorting to the idea of irradiation, we try to get an explanation from the idea of an ultimate equalization of excitement of the sentient elements by the gradual blunting of the sensibility of those most highly stimulated, till they convey to the mind no more idea of lucidity than their neighbours which are far less stimulated, we are troubled to account for the absence of those transitions in colour which occur in the *spectra* of images.

In any case the same difficulty besets us here as in most other cases where we try to define the laws that regulate nervous action; we find it hard to make any statement with respect to them which our own minds shall entirely approve.

We have evidence which cannot be gainsaid that impressions made upon a portion of the field of view may physiologically produce an influence upon the aspect of other portions. The well-known phenomenon of physiological accidental colours supplies an instance of this:—Thus, if there be two holes in a window-shutter, one of which admits freely the light of day, whilst a piece of coloured glass covers the other, the shadows of objects which are thrown in the light that has entered the room through the medium are of its supplementary colour. But this does not happen unless the space occupied by the shadow is illuminated with white light, and, therefore, not unless the retina opposed to what seems to be the accidental colour is itself stimulated. However, this is a physiological production, not of the same, but of another sensation, and is not a gradual, but an instantaneous effect.

Volkmann has recently published an essay upon irradiation,* in which he cites a great number of ingeniously conceived experiments which he performed, having reference to the subject. From some of these he concludes that, under certain conditions, both white spots on a dark ground and dark spots on a white ground, may appear *appreciably* larger than they ought to do judged of geometrically. He goes so far as to infer that this physiological irradiation is not a retinal effect, but is owing to the operation of the sensorium.

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* Physiologische Untersuchungen im Gebiete der Optik, von Dr. Alfred Wilhelm Volkmann, Professor in Halle. Leipzig, 1863.

Nevertheless, he gives no instance of either a dark, grey, or white spot, or line, on another sort of ground, being obliterated by irradiation. But the kind of irradiation which he does observe he finds to be liable to increase by the retina being exposed at one spot to a stimulation lasting for some continued time.

I cite these facts in irradiation to show how complex is the problem of solving the nature of phenomena in which its supposed action may come into play; but I must refrain from being led away here into studies which do not lie within the scope of the design of this essay.

66. I have now discussed, as far as I am aware all the essential mechanical disturbances that may interfere with the regular performance of the retinal functions and have shown that there are optical indices of a differential constitution in the composition of the bed of sentients in different parts of the retina. With a few words on the probable properties and seat of the sentients, I shall bring my labours to an end.

Our visual experience teaches us that the district of the so-called foramen centrale possesses usually the highest distinguishing power, and that this power diminishes from it to the ora serrata. This rate of diminution is perhaps proportional to that of the number of cones (not rods) that may be counted in equal areas from the middle to the termination of the retinal expansion. They are also normals to the retina, as seems necessary to the ultimate sentients.

These facts all seem to point to the cones as the chief if not sole sentient elements; and to be justly used by Kölliker and H. Müller, and previously, more or less, by Donders, as proofs that the bacillar layer of the retina is the true sentient. H. Müller finds that the breadths of the retinal images of the least interstices distinguishable by the eye, about equal the diameters of the finest cones, and argues that therefore these are the ultimate sentients. In respect to this, however, Volkmann, in the essays just quoted, affirms that we can certainly distinguish interstices of half the breadths of those ascertained by Müller, showing that with regard to the question of the size of the ultimate sentient, there is still some doubt; if not as to what the ultimate sentient may be.

In connexion with this objection of Volkmann's, we may recollect the fact that when a surface applied on the outside of the eye depresses the sentient periphery, the sentients are not stimulated where the depression occurs, as if their outer ends were not excitable, but where they are laterally squeezed together. Thus it may be that they are only acted upon by the light which impinges upon their sides; and it may be that the whole circumferential wall of a cone is not limited to the production of a sole sensation at one time. And if it be that the most sensible area of the retina is really lodged in a pit, the purpose of this may be to guard the elements it contains against lateral compression.

At any rate, the phenomena observed in external depression afford a presumption that the outer ends of the cones do not present the sentient surface, though it should be that we are unable to support this conclusion from the halo around lights which are looked at obliquely (52) :—A presumption that aids us in limiting the position of the sentient surface from without, as the parallaxes of the shadows of central retinal vessels afford us proof that it has decided limits on the inner side.

H. Müller imagined that the radial fibres (3) which he discovered passing from the bacillar elements to the limitary membrane were the channels by which the sensations were conducted from them to the optic nerve-fibres; but it has been now agreed among microscopists that they are not of nervous material, and that the true path of conduction has, in the human eye at least, yet to be determined.

67. Many serious physiological blunders have resulted from inattention to the perturbations to which vision is liable from the disturbing causes touched upon in this chapter, especially in cases where the eye is *strained*, or compelled to look long in any one direction;—for example, the vanishing of objects from the field (61) of view has been regarded as instances of fitful irradiation of sensation. In the same way these causes have led to the notion that the retina, or optic nerve, or brain is diseased. The confusion has been much increased by the usually coincident disturbances of sight from (31) irregular action of the ciliary muscle and iris. I spoke of these sources of error in 1856, and other writers have discussed more or less of them. I have endeavoured so to put my notes in this *appendix* together, as to let the reader have a general idea of the *history* of the investigations mentioned. I am not in a position at

present to give a more particular history, nor does it fall in with the design of this essay to give it. I do not undertake to treat of the general properties of the retina, any more than of those of the refracting media of the eye.

Whilst I am correcting the printer's last proof, there reaches me, "Donders on the Anomalies of Accommodation and Refraction of the Eye,"—a book prepared by the author himself for the New Sydenham Society. As it contains an article on Entoptics, I am put in possession by himself of his views upon the subject. He tells us that it was he, rather than Doncan, who originated the statements I have criticized at p. 124. His present version (so far as it goes) so nearly coincides with that in Karsten's Encyclopædia that he seems to have neglected the study of late years, and to be unconscious of any recent attempts to improve it.

I may add here that the word Entoptics was first used by Listing.

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